INTERFERENCE OF SMOOTH PIGWEED AND COMMON PURSLANE
WITH LETTUCE AS AFFECTED BY PHOSPHORUS FERTILITY

By

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ACKNOWLEDGMENTS

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Greenhouse and field trials were conducted at the University of Florida from May 1995 to December 1997 to determine the effect of phosphorus (P) fertility on the interference of smooth pigweed (*Amaranthus hybridus* L.) and common purslane (*Portulaca oleracea* L.) with lettuce (*Lactuca sativa* cv. South Bay). Replacement series, additive, removal time, partitioning above and below ground and P depletion studies were performed. Common purslane growth was responsive to P fertilization, while smooth pigweed was not. Greenhouse replacement series studies indicated that both weeds were more competitive than lettuce regardless of P rate. However, high P fertility enhanced lettuce's competitive ability against smooth pigweed, whereas no effect on the crop competitiveness was observed in lettuce-common purslane mixtures.

Additive and removal time studies conducted under field conditions demonstrated that banding P directly in-row with lettuce as opposed to broadcasting, increased the smooth pigweed critical density necessary to reduce lettuce yield and quality, as well as increasing the time frame of crop-weed competition without significant yield losses. On the other hand, common purslane critical density was not affected, while removal time was delayed when banding P was compared with broadcast application. In general, banding P resulted in higher lettuce yields compared with broadcast application, regardless of the density or initial removal time.

Partitioning studies showed that smooth pigweed-lettuce interference occurred both above and below ground. Light interception appeared to be the primary mechanism of interference, whereas luxurious P consumption by smooth pigweed was a secondary mechanism. Common purslane-lettuce interference was primarily characterized by P absorption at the expense of lettuce, with the secondary mechanism being competition for light. As revealed by P depletion studies, both weeds initially absorbed P more rapidly than lettuce, with common purslane being the most aggressive acquiring this essential element.

Data obtained indicated that P fertilization methods (i.e. banding) may be utilized effectively by farmers, producers and researchers to reduce and delay the negative impact of smooth pigweed and common purslane in lettuce production as a cultural management strategy.

As a vegetable crop, lettuce (*Lactuca sativa* L.) is considered the most important among all the leafy salad crops in the world, including celery (*Apium graveolens*, Apiaceae), endive and chicory (*Chicorium endivia* and *C. intybus*, Asteraceae) (Janick 1986). In the United States, lettuce is commercially grown during the cool-season in 15 different states, and in many states there are numerous large home-garden production systems (Hartmann et al. 1984).

During the 1996 growing season in the United States, approximately 114,000 hectares of different lettuce types were planted, representing about $1,425 million (USDA 1997). California, Arizona, Texas and Florida are the leading lettuce production states in the United States. In Florida, major growing areas are concentrated in the organic soils (Histosols) of the Everglades Agricultural Area (EAA), and Lake Apopka (Fla. Agric. Stat. Serv. 1997).

Weed-free lettuce production is thought to be needed to obtain maximum marketable yields. Weed management is an important and costly factor in lettuce production on high organic matter soils, because of the lack of available herbicides and the reliance on expensive hand-labor. Weeds cause yield losses because of crop interference. Interference occurs in two ways: a) competition, in which limited essential growth and

development factors such as light, water, space and nutrients are removed by the weeds at the expense of the crop, and b) allelopathy, in which weeds release growth-inhibiting substances into the soil as root exudates and/or from decaying plant material (Anderson 1983).

The concept of a weed-free stand is usually unpractical, leading to excessive use of economic inputs and reduced profits. Therefore, implicit knowledge about weed populations and their effects on lettuce production is necessary, as well as a clear understanding of the specific interactions between commonly occurring weeds and lettuce, thus management strategies can be developed.

Smooth pigweed (*Amaranthus hybridus* L.) and common purslane (*Portulaca oleracea* L.) are two of the most troublesome weeds in lettuce fields in the EAA. Due to the lack of labeled herbicides to control these two weeds, hoeing and cultivation are used to manage these species. These control methods are costly, time-consuming and can damage the shallow root system of lettuce resulting in depressed yield. Therefore, alternative cultural weed management strategies have to be devised that can reduce the impact of these two weeds in lettuce stands. Cultural weed management utilizes the enhanced competitive ability of crops to counteract the competitive effects of weeds, by either utilizing improved and more vigorous crop varieties or managing essential factors, such as P, in favor of the crop (Anderson 1983).

Soils in the EAA are classified within the order Histosols, meaning that a minimum of 20 to 30% organic matter can be found in the upper layer of the soil profile (Snyder 1994). These soils are commonly referred to as muck soils or organic soils. Phosphorus

(P), an essential macroelement for plant growth and development, is naturally deficient in organic soils of the EAA. Consequently, supplementary P fertilization is utilized in lettuce fields. Unfortunately, P amounts applied to lettuce are also available to weeds, including smooth pigweed and common purslane; therefore competitive relationships are established. Because of the nature of organic soils, immobile phosphate ions are either lost by leaching or runoff, or taken up by growing plant roots (Sanchez and Porter 1994).

In order to obtain a better understanding of the effect of smooth pigweed and common purslane on lettuce production as affected by P fertility, research was conducted separately with each weed-lettuce complex to ascertain the competitive relationships. The null hypotheses in this research were as follows:

a) There are no intraspecific and interspecific competitive interactions between either weed and lettuce under varying P rates.

b) There are no effects of varying P fertility regimes and densities of either weed on lettuce yields.

c) There are no effects of varying P fertility regimes and initial removal times of either weed on lettuce yields.

d) There are no above and below ground interactions between either weed and lettuce as affected by varying P rates.

e) There are no effects of the weeds involved on the P absorbed amounts by lettuce.

CHAPTER 2
LITERATURE REVIEW

Lettuce Description

Lettuce (*Lactuca sativa* L.) is a vegetable crop belonging to the Asteraceae family (formerly Compositae). This species was known to be cultivated in the royal gardens of Persian kings more than 2500 years ago (Doty 1990; Hartmann et al. 1984), and it is considered to be native to the Mediterranean region and inner Asia Minor (Swiader et al. 1992; Peirce 1984). It seems that domesticated species were first derived from wild or prickly lettuce *(L. serriola)*, which was commonly found growing as a weed in early gardens (Janick 1986; Hartmann et al. 1984). Cultivated species were introduced in Central and South America in 1494 (Peirce 1984).

Lettuce cultivars are grouped into four major categories: crisphead, butterhead, leaf and romaine. Crisphead lettuce cultivars are characterized by firm heads with brittle texture and leaves tightly folded. Outer leaves are large and dark green with prominent midribs and veins, while inner leaves are white to yellow. Cultivars in this group show good tolerance for shipping long distances. Most lettuce produced in the United States belong to this group. The most common cultivars are 'Great Lakes', 'Iceberg', 'South Bay' and 'Raleigh'. When planted directly from seeds, maturity is usually obtained between 60 and 80 days (Maynard et al. 1995; Peirce 1984; Swiader et al. 1992).

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Butterhead cultivars have loosely folded leaves, where outer leaves are either reddish or green, and inner leaves are either white or yellow depending on the cultivar. Veins and midribs are less prominent than in crisphead cultivars. 'Bibb', 'Dark Green Boston' and 'Buttercrunch' are common cultivars. Since leaves can bruise and break easily, shipping and handling requires care. Harvesting occurs between 45 and 55 days after planting (Maynard et al. 1995; Peirce 1984; Swiader et al. 1992).

Leaf cultivars are popular among home gardeners and local markets. Leaves are open and form a compact rosette, without forming heads. Outer leaves are frilled and crumpled with variable margins and color varying from light green to reddish. 'Black-Seeded Simpson', 'Grand Rapids' and 'Slobolt' are some of the most common cultivars. Leaf lettuce is not adapted for long distance shipment and its shelf life is short. Harvest takes place between 40 and 50 days after planting (Maynard et al. 1995; Peirce 1984; Swiader et al. 1992).

Romaine cultivars, also known as cos cultivars, grow upright and cylindrical to 20 to 25 cm high. Leaves are tightly folded with heavy midribs. Outer leaves are dark green, while inner leaves are light green with fine texture. 'Dark Green Cos', 'Valmaine' and 'Paris Island' are extensively planted. These cultivars show intermediate tolerance to shipping procedures. Maturity is reached between 45 and 55 days after planting (Maynard et al. 1995; Peirce 1984; Swiader et al. 1992).

Although recent progress have been made in acclimation of lettuce cultivars to high heat conditions, this crop is considered a cool-season vegetable (Peirce 1984). In Florida, planting dates for different lettuce groups are between the first week in September

and the third weed in March (Maynard et al. 1995). Germination is usually favored by cool temperatures ranging from 18 to 21°C (Peirce 1984). Temperatures of 26°C or above can prevent germination or result in uneven stands. Soil moisture is critical at planting to ensure proper seedling establishment (Swiader et al. 1992). In the organic soils of the EAA, appropriate moisture levels are obtained by subirrigation or sprinklers.

The lettuce root system is characterized by a shallow network of fibrous roots that spreads 45 to 60 cm from the soil surface, with the bulk growing vertically within the first 20 cm of soil (Guenkov 1966). Because of this morphological characteristic, irrigation and fertilization practices must be as efficient as possible to provide the crop appropriate amounts of water and nutrients.

Smooth Pigweed Description

Taxonomy, Origin and Distribution

Smooth pigweed (*Amaranthus hybridus* L.) is an annual species belonging to the class Angiospermae, subclass Dicotyledoneae, order Centrospermae and family Amaranthaceae (Marcano 1981). This family is characterized by herbaceous plants with entire opposite leaves, sometimes alternate in the stem, without stipules, and small green to white perfect flowers in seedheads (Marcano 1981).

More than 20 species in the Amaranthaceae family are known to be noxious weeds (Fla. Agric. Ext. Serv. 1984), with most of these comprised in the *Amaranthus* genus, although other genera such as *Alternanthera, Achyranthes, Celosia and Floelichia* contain species considered weeds (Fla. Agric. Ext. Serv. 1984; Murphy et al. 1994).

Smooth pigweed is native from eastern North America, Central America, the Caribbean and northern South America (Southern Weed Sci. Soc. 1994). This weed is commonly found in temperate regions throughout Africa, Asia and Australia, and it has been reported as an important weed in 27 crops in 27 countries (Holm et al. 1991; Murphy et al. 1994). In the United States, it ranges from the delta region of the Mississippi River to east and south of Wisconsin (Southern Weed Sci. Soc. 1994).

Morphological Characteristics

Amaranthus hybridus grows as a tall, erect plant, with glabrous to sparsely hairy green to brownish stems that can reach up to 150 cm tall. Leaves are glabrous, simple, lanceolate to ovate, alternate, with long petioles up to 5 cm long. Blades can be 15 cm in length, terminated in a short and sharp tip. Tap roots are well developed and could reach up to 150 cm deep, forming an intricate network of secondary, tertiary and quaternary roots (Holm et al. 1991; Martin 1972; Murphy et al. 1994; Southern Weed Sci. Soc. 1994).

Perfect flowers are contained in tightly arranged terminal or axillary panicles, and green in color. Fruits are contained in a dehiscent utricle, wrinkled and rough when dry, and 1.5 to 2 m long. Seeds are brown or black, with a shiny coat, and 1 mm long. Around 100,000 to nearly 200,000 seeds can be produced in a single season (Holm et al. 1991; Martin 1972; Murphy et al. 1994; Southern Weed Sci. Soc. 1994).

Growth Habit and Management

Smooth pigweed can grow nearly in almost every soil condition as long as the seed bank contains enough viable propagules. This weed takes advantage of its rapid initial growth to compete against crops. Germination usually occurs shortly after seed shedding, although some dormancy mechanisms have been associated with lack of light, especially following imbibition (Holm et al. 1991).

Even though, the distribution range of *A. hybridus* appears to be wide in terms of temperature, this weed thrives in warm climates. Most reports concerning smooth pigweed interference in crops originates from Latin America and the southern United States in studies with field and vegetable crops. Yield losses have been attributed to shading because the weed can quickly shade short-statured crops (Holm et al. 1991).

Among the several weed management methods that can be implemented for control of smooth pigweed, chemical, mechanical and cultural methods seem to be the most common. Chemical control implies the use of herbicides to achieve adequate reduction of weed populations in crop stands. Mechanical control relies on the use of hoeing, cultivation, mowing, and hand-pulling. Cultural control is based on the use of enhanced crop competitiveness against weed populations (Anderson 1983).

In field crops, such as corn, excellent to good (100 to 80% control) smooth pigweed control can be achieved with preemergence atrazine or pendimethalin, and 2,4-D, dicamba or bromoxynil postemergence. In soybeans, the same degree of control is obtained by using alachlor, dinitroanilines (i.e., trifluralin), linuron, imazethapyr and metribuzin preemergence, and lactofen, chlorimuron or imazethapyr postmergence. In

cotton, pendimethalin, norflurazon or fluometuron preemergence, and MSMA in combination with fluometuron, cyanazine, oxyfluorfen or linuron postemergence provides excellent control of *A. hybridus* (Foster et al. 1996).

In vegetable crops, excellent to fair smooth pigweed control can be attained with preplant incorporated applications of clomazone, DCPA, imazethapyr, metribuzin, napropamide or trifluralin. Preemergence applications of atrazine, clomazone, DCPA, imazethapyr, linuron, metribuzin, metolachlor, naptalam, oxyfluorfen or pendimethalin are recommended to control this weed. Postemergence applications of atrazine, bentazon, bromoxynil, imazethapyr, linuron or metribuzin have been shown to control *A. hybridus* effectively (Stall et al. 1996).

Only imazethapyr is currently labeled to control broadleaf weeds in lettuce produced on high organic matter soils, such as smooth pigweed. This herbicide can be used preemergence and postemergence (Stall et al. 1996). Therefore, other weed management alternatives have to be explored to reduce the impact of this weed in lettuce production. Mechanical control has proven to be costly, time-consuming and can injure the shallow root system of lettuce. In turn, cultural weed control has been shown to be a valuable alternative to improve crop competitiveness and/or to reduce weed interference (DiTomaso 1995).

Previous research conducted with spiny amaranth (*A. spinosus*), a related species, and lettuce demonstrated that banding phosphorus (P) beneath each lettuce row compared with broadcast applications reduced the negative impact of spiny amaranth on lettuce growth (Shrefler et al. 1994). In the same study, the authors suggested that banding P

gave an additional advantage to lettuce to uptake P prior to nutrient absorption by the weed. Luxurious P consumption appeared to be a major factor in the interactions of this weed and the crop (Shrefler et al. 1994).

Common Purslane Description

Taxonomy, Origin and Distribution

Common purslane (*Portulaca oleracea* L.) is classified in the class Angiospermae, subclass Dicotyledoneae, order Centrospermae and family Portulacaceae (Marcano 1981). Succulent aerial parts, with alternate or opposite glabrous leaves, and hermaphrodite flowers characterize species belonging to this family (Marcano 1981). Three genera are known within the Portulacaceae family comprising 13 species (Fla. Agric. Ext. Serv. 1984). Another species known in this family is *P. amilis*, which is considered a turfgrass weed (Murphy et al. 1994).

There is conflicting information about the center of origin of this weed. Some reports indicate that *P. oleracea* may be native of subtropical regions in western Asia (Southern Weed Sci. Soc. 1994), whereas others suggest that this weed may have originated in northern Africa (Holm et al. 1991). In spite of the discrepancy concerning the origin, researchers agree that common purslane was introduced to North and South America from Europe, where it was considered one of the early vegetables.

Common purslane has been reported a noxious weed in 45 crops in 81 countries throughout the world (Holm et al. 1991). It is a common weed in the tropical and subtropical regions, although it can tolerate cool temperatures near freezing. This weed

can be found in Canada, Argentina, Germany, South Africa, Australia, India, and the Caribbean. In the United States, *P. oleracea* is present nationwide, being more abundant in the eastern third of the country and more scattered in the Pacific Northwest (Martin 1972; Murphy et al. 1994; Southern Weed Sci. Soc. 1994).

Morphological Characteristics

Common purslane is a fleshy annual weed, which can grow either prostrate or erect up to 50 cm long. Stems are smooth, purple or red, and highly branched. Leaves are thick with rounded tips, and without petioles. Blades are 0.4 to 2.8 cm long, and 0.6 and 2 cm wide. Roots can be formed at stem nodes and may reach up to 60 cm long (Holm et al. 1991; Martin 1972; Murphy et al. 1994; Southern Weed Sci. Soc. 1994).

Flowers are complete with 5 yellow petals tightly inserted in the calyx, and 6 to 12 stamens arranged in a tightly terminal cluster in branches. Fruits are globular with multiple seeds, 4 to 8 mm long, 3 to 5 mm wide, in dehiscent capsules. Seeds are black, nearly oval, about 0.5 mm in diameter and length, with wrinkles on the outer coat. Almost 10,000 seeds can be produced by one plant (Holm et al. 1991; Martin 1972; Murphy et al. 1994; Southern Weed Sci. Soc. 1994).

Growth Habit and Management

Common purslane is widely distributed throughout the world, thriving in gardens, fields, lawns and waste places up to 2700 m elevation. The complete life cycle of this weed may take 2 to 4 months, depending on air temperature, with warmest conditions hastening growth. Seedling emergence may occur 2 days after imbibition (Holm et al. 1991).

Plants are indifferent to photoperiod and can flower over a range of 4 to 24 hours of light, even though quantitative changes have been observed with increased flowering up to 12 hours of light, decreasing afterwards. Young plants grown under low light tend to be erect, whereas the opposite is true for plants under high light conditions. Seeds are the main propagation means for this weed, although cuttings produced from hoeing or any other mechanical disturbance can quickly produce roots and whole new plants. Wind and water seem to be the main dispersal agents of common purslane seeds (Holm et al. 1991).

Mechanical weed control is frequently used to manage this weed. However, due to the ability of this weed to rapidly resprout from cuttings, this control method has its limitations in reducing common purslane populations in crops. The resprouting ability is due to its Crassulacean Acid Metabolism (CAM), which enables cuttings to withstand uprooting for several days, weeks or even months, growing adventitious roots from nodes and establishing new plants (Ku et al. 1981). Several herbicides are currently labeled to control *P. oleracea* in field corn, including atrazine, chloramben, alachlor, metolachlor, pendimethalin, propachlor and EPTC preemergence or preplant incorporated. Cyanazine, alachlor, linuron and trifluralin are used postemergence (Foster et al. 1996).

In soybeans, alachlor, chloramben, clomazone, ethalfluralin, glufosinate, metolachlor, naptalam, pendimethalin, trifluralin or vernolate are recommended preemergence or preplant incorporated, whereas acifluorfen, bentazon, fomesafen, imazethapyr, lactofen, linuron or metribuzin are labeled postemergence (Foster et al. 1996).

For Florida vegetables, current recommendations provide excellent to good (100 to 80%) control of this weed with applications of clomazone, DCPA, imazethapyr, metolachlor, metribuzin, napropamide or trifluralin preemergence or preplant incorporated. Postemergence applications of atrazine, bentazon, bromoxynil, linuron or metribuzin have provided good common purslane control. Imazethapyr, which is labeled for preemergence and postemergence broadleaf weed control in lettuce provides good to excellent control (80 - 100%) preemergence but only poor to fair control (<80%) of common purslane when used postemergence (Stall et al. 1996). Thiobencarb preemergence provides good control of common purslane, however, is sometimes phytotoxic to the lettuce.

Weed Interference

Ecological Aspects

Ecology is defined as the science that studies the dynamic order and relationships of organisms with respect to their surrounding environment (Silvertown 1987). In the broad sense, weed ecology searches for the changes that occur in the abundance, distribution and structure of populations of weed species (Cousens and Mortimer 1995). Basic ecological concepts, such as means of dispersal, colonizing potential and regeneration capacity can be used to examine the interactions occurring among weeds and crops, providing valuable insight for the development of novel techniques that could lead to improved weed management programs.

Means of dispersal play a significant role in the overall ability of a given species to

invade new areas (Cousens and Mortimer 1995). Two well known dispersal means are considered when describing reproduction: sexual and asexual. Sexual reproduction is achieved when seeds are produced by a combination of male and female gametes, whereas asexual reproduction involves production of new plants from vegetative plant parts, such as stolons, cuttings, tubers, rhizomes and bulbs (Silvertown 1987).

Colonizing potential is related to the ability of a given species to dominate a given area (Cousens and Mortimer 1995). The fact that a species is introduced in a region does not guarantee that it will become a weed. It must be able to displace other individuals present in that habitat and create its own niche within the plant community to become a weed.

Regenerative capacity indicates how persistent the species is in the new habitat (Cousens and Mortimer 1995). In other words, if the species is to become established within the community, it must undergo widespread dispersal, generation after generation. Time seems to be the key component in this instance, since the invasive species has to maintain a sustained growth rate until community equilibrium is established.

In most cases, these described characteristics determine how aggressive a weed species is with respect to other plants. It is well known that aggressive competitors have the potential to reproduce rapidly from seeds and/or by vegetative means, enabling them to colonize and become established in empty niches more quickly than slow-growing species. Several examples can be noted in this regard. Among the most typical aggressive species are *Sorghum halepense*, *Avena fatua* and *Cyperus rotundus* (Cousens and Mortimer 1995).

Interference: Allelopathy and Competition

Interactions occurring among plant species growing in proximity are called interference (Radosevich et al. 1997). A basic requirement for interference is that essential resources must be in limited supply for the individuals involved. Two plant interactions commonly found are competition and allelopathy. In practical terms, these two components are considered together to comprise interference.

Allelopathy can be defined as the release of toxic or growth-inhibiting substances into the soil as root exudates or leachates from dead and/or decaying vegetative matter, reducing or eliminating growth of other plants (Anderson 1983; Patterson 1986). The most typical allelopathic compounds found to be released are terpenoids, steroids, phenolics, flavonoids, alkaloids and tannins (Patterson 1986). These allelochemicals are usually produced as secondary by-products of primary physiological pathways in plants, such as the shikimic acid pathway (Salisbury and Ross 1984).

Both crops and weeds can be allelopathic. Among the top 20 worst weeds in the world, the following 13 weeds have been reported to have some type of allelopathical properties: johnsongrass (*Sorghum halepense*), purple nutsedge (*Cyperus rotundus*), yellow nutsedge (*C. esculentus*), large crabgrass (*Digitaria sanguinalis*), itchgrass (*Rottboellia exaltata*), bermudagrass (*Cynodon dactylon*), cogongrass (*Imperata cylindrica*), wild oats (*Avena fatua*), spiny amaranth (*Amaranthus spinosus*), common purslane (*Portulaca oleracea*), field bindweed (*Convolvulus arvensis*), giant foxtail (*Setaria faberii*) and quackgrass (*Agropyron repens*) (Holm et al. 1991). Celery (*Apium graveolens*) has been shown to be allelopathic to weeds and crops such as spiny amaranth,

barnyardgrass (*Echinochloa crus-galli*), wild mustard (*Brassica kaber*), radish (*Raphanus sativus*), escarole (*Cichorium endivia*), and lettuce (Bewick et al. 1994).

When studying allelopathic effects of a given species, it is relatively easy to show that residues and/or extract can inhibit or hinder growth of another species. However, it is more difficult to demonstrate clearly that in fact a specific compound or compounds produced by the allelopathic species results in growth inhibition of another plant, since allelochemicals must be isolated, identified and reapplied to the target species. If the compound is the cause of the allelopathic effect, symptoms similar to those observed in field trials should occur (Fuerst and Putnam 1983). The downside of this approach is that sometimes allelochemicals are too unstable and/or too hard to isolate to show effects.

Generally speaking, when studying interference between two species, researchers determine first whether other factors such as light, water, nutrients, space or gases are causing significant interactions. If the answer is negative then allelopathy can be assumed to be responsible, leading to further bioassays involving leaf leachates, root residues and decayed litter (Patterson 1986).

Competition refers to the mutually adverse effect of plants that utilize resources in limited amounts (Anderson 1983; Radosevich et al. 1997). This concept must be distinguished from amensalism, which refers to only one species being affected while the other remains stable (Burkholder 1952). Two responses are usually observed in competitive communities: plasticity and mortality. Plasticity implies the reduction of dry matter accumulation and/or biomass redistribution being affected by a neighbor. Mortality takes place when competitive levels are so intense that plasticity tolerance is surpassed.

Traditionally, two definitions of competition have been enunciated based on the responses observed between neighboring species. Grime (1977) stated that competitive ability is related to the ability of individuals to tolerate low levels of limited resources more efficiently than their neighbors, whereas Tilman (1982) relates competition to the effectiveness of the population to capture resources more rapidly than their neighbors. The first definition is based on the mechanism of competition, while the second one focuses on the outcome of the interaction. Ultimately, weed ecologists are interested in both aspects of competition: a) how different mechanisms of competition affect the population over time, and b) how the aggressiveness of one species affects the number of individuals of another species in a given area. Regardless of theory accepted, the status of limited resouces, namely water, light, nutrients, space and gases, has to be determined before undergoing any type of competition study.

Weeds actively interfere with crops resulting in stress and yield reduction. Numerous studies have focused their attention in quantifying crop loss due to weed interference. However, scarce research has been conducted to determine the mechanisms of interference in weed-crop settings. In order to determine the extent and the nature of weed interference, several experimental techniques have been developed. These experimental methods will be described in the next section.

Weed Interference Experimental Methodology

Intraspecific and Interspecific Competition

Before offering a detailed explanation about the different methods to determine

weed competition, it is necessary to define two basic concepts that will appear throughout

the discussion of the varying types of experiments. Intraspecific (*intra-*: from Latin,

within) competition refers to the mutually adverse effect that individuals of the same

species have on one another. Interspecific (*inter-*: from Latin, between, among)

competition refers to the adverse influence that individuals of different species have on

each other.

Both types of competition will follow specific ecological trends depending upon

the species involved. For instance, competition in monocultures can be manifested in three

different aspects: a) constant final yield law, b) plasticity, and c) mortality (Firbank and

Watkinson 1990).

Under constant final yield law, individual plant biomass produced per unit of

surface area decreases as the total number of individuals per area (density) increases (Kira

et al. 1953). As density increases, an equilibrium is achieved with no further decrease in

biomass occurring without causing mortality. At this point, it is understood that the

system became limiting in terms of available resources. In low density situations,

differences in biomass per plant may not be found since individuals may be too far apart to

interfere with each other.

A basic assumption of the constant final yield law is that plants are spaced

uniformly over the surface area. This assumption provides equal zone of resource

depletion for each individual in the system (Firbank and Watkinson 1990). In terms of the overall biomass production per area, constant final yield law indicates that total plant biomass in a given area will increase with density until a critical density is reached where no further increments in plant biomass are found (Radosevich 1987). Various equation models have been proposed since the introduction of this law (Bleasdale and Nelder 1960; de Wit 1960; Shinozaki and Kira 1956). The most recent equation uses log-log scales to show the relationship between density and dry weight per plant (Firbank and Watkinson 1990).

Changes in plant size due to competition are called plasticity effects (Firbank and Watkinson 1990). These changes are a direct consequence of the law of constant final yield, where an increase in density causes reductions in biomass accumulation by individual plants. If the competition for essential factors increases beyond a given threshold, mortality or self-thinning takes place in the population, allowing the remaining individuals to take advantage of the empty spaces and redefine competitive relationships with new neighbors until equilibrium is reached within the population (Firbank and Watkinson 1990).

Methods for Studying Competitive Interactions

Various methods have been developed to study competitive interactions between weeds and crops. Within each approach, three factors have to be considered: a) density, b) proportion or ratio, and c) spatial arrangement. Density is defined as the number of plants per unit surface area. Regardless of method, varying densities of species allows inferences about intraspecific competition in the system. Proportion is the range of substitution of

one species for another in the system. Basically, conclusions about interspecific competition can be obtained by comparing plant growth of species at varying proportions. Spatial arrangement is how individuals are arranged within a particular area (Radosevich 1987; Silvertown 1987).

There are four different approaches that can be used to study competitive interactions: a) additive, b) substitutive, c) systematic, and d) neighborhood (Oliver and Buchanan 1986; Radosevich 1987; Silvertown 1987). Each one has a different objective and use, but all consider three factors: density, proportion and spatial arrangement. In the additive study, the density of the crop is maintained constant while the weed density is varied. Crop yield usually improves as weed density decreases, until the crop cannot increase its yield in response to further decreases in weed density. This approach allows the researcher to determine the critical weed density, that is, where significant yield reductions are obtained. Since the crop is planted in a uniform pattern, intraspecific competition by the crop is assumed to remain constant. This type of study is more suitable for field conditions than for greenhouses (Oliver and Buchanan 1986; Radosevich 1987; Silvertown 1987).

The substitutive approach, also called replacement series, is designed basically for greenhouse studies. In replacement series studies, densities remain constant and the proportion of each species is varied from the monoculture of one species at a given density to the monoculture of the other species at the same density. This approach allows the researcher to quantify the relative competitiveness of the weed with respect to the crop and vice versa (Oliver and Buchanan 1986; Radosevich 1987; Silvertown 1987).

Systematic experiments are restricted to the study of competition among individuals of the same species. Plant densities and spatial arrangement are varied systematically. There are two basic designs for this kind of experiment, one in which plants are arranged either in rows, the other in circles or fan-shape distributions (Oliver and Buchanan 1986; Radosevich 1987; Silvertown 1987).

The neighborhood approach focuses on the yield of one individual plant in the presence of varying densities of plants of another species. The response of that individual plant to "spheres of influences" is the important target under this approach (Radosevich, 1987).

Relative Yield

Some variables are calculated in replacement series studies based on the growth of individuals in mixtures versus monoculture. For example, relative yield (RY) is used to interpret competitiveness of each species (Rejmanek et al. 1989). An increase in this variable suggests enhanced competitive ability by that species. Due to the nature of this approach no direct inferences can be translated to field conditions, instead relative trends can be determined.

This variable is obtained using the following equation:

$$RY = W_{mix}/W_{mono} \qquad [1]$$

where W_{mix} represents the shoot dry weight per container of the species involved in mixture, and W_{mono} is the shoot dry weight per container in monoculture.

Time of Removal Studies

It is generally considered that yield reduction due to weed competition occurs during the first part of the growing season. It is important to determine the impact of a given duration of competition particularly early in the season where weeds are most troublesome and methods of control are normally imposed. Using this approach, a predetermined weed density is established in the field along with the crop. Weeds are then removed from the field at varying time intervals after establishment from the planting date. A weed-free control and a weedy season-long treatment are also established. As a result, significant growth and/or yield reductions due to weed competition for a given period of time can be detected, as well as determining when it is not economically feasible to implement some type of control measure (Radosevich et al. 1997).

Partitioning Studies

In order to determine the mechanisms of weed interference, partitioning studies are conducted to separate the above-ground effects of the shoots from the below-ground effects of the roots or other subterranean structures. In this approach four treatments are established: a) full competition, b) no competition, c) below-ground competition, and d) above-ground competition (Berendse and Elberse 1990; Groves and Williams 1975; Silvertown 1987).

In full competition treatments, two plants (one plant of each species) are planted in a given volume of soil and aerial space. In no competition, one plant of each species is planted separately in half of the soil and aerial volume. The basic assumption is that if

competition is occurring, biomass of plants growing under no competition will be greater than those growing under full competition.

In above-ground competition treatments, both plants are planted in the initial volume, but the container will be divided in two equal chambers where each species will develop roots separated from the other. Only shoots will be allowed to compete for radiant energy. If these treatments are found to be equal to the no competition treatment then light is not the primary factor of competition between these two species. If above-ground competition treatments are different from the no-competition control, light is one possible mechanism of competition.

In below-ground competition treatments, two equal aerial chambers are provided, where roots are allowed to compete. If biomass values per plant indicate that no differences are found with respect to the full-competition treatment, then under-ground competition is assumed to be the only mechanism occurring. Further variations in the amounts of water, nutrients and space provided will determine the specific mechanism utilized by the species involved in the interactions.

Competition for Plant Nutrients

Generalities on Plant Nutrients

Essential plant nutrients are elements needed by plants to successfully complete their vegetative cycle. They are taken up from the soil, water and air. Deficiencies occur when a specific element is not present in required amounts. Plants showing deficiency symptoms would regain their normal appearance only by supplying the deficient element.

No element can be totally replaced in its function by another element (Salisbury and Ross 1984).

There are 16 essential elements for plant growth. Based on their relative amounts in plant tissues, essential nutrients have been classified in 2 distinctive groups: a) macronutrients (*makro-*: from Greek, large), which are required in large amounts, and b) micronutrients (*mikro-*: from Greek, small), which are taken up in lesser amounts. Macronutrients are carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The first three are obtained from the air and water, whereas Ca and Mg have to be absorbed from the soil. Sulfur can be present in the air, water and soil. Micronutrients are iron (Fe), manganese (Mn), copper (Cu), Zinc (Zn), molybdenum (Mo), boron (B) and chlorine (Cl). In most cases, these elements are obtained from the soil, although Cl can be absorbed from water rich in sodium chloride or other salts (Brady 1990). Because the soil supply of these essential nutrients is limited for agriculture, additional amounts are applied to the soil in the form of fertilizers to supplement plant nutrition.

Weed-Crop Competition for Nutrients

In most natural environments, nutrients play a major role in affecting the dynamics of plant populations. Experiments dealing with supply of N and P have shown dramatic changes in plant dominance (Berendse and Elberse 1990). In agriculture, these trends hold true for most crops. Along with K, N and P can be the most influential plant nutrients in changing the balance of competition in a given crop setting. The addition of a given nutrient can promote growth of either crops or weeds when applied in crop-weed

associations (DiTomaso 1995). In many cases, increases in weed growth rate have been attributed to enhanced competitiveness due to the presence of larger nutrient amounts, further depressing crop yields. Okafor and DeDatta (1976) showed that purple nutsedge (*Cyperus rotundus*) was able to utilize increasing N rates better than rice, therefore gaining advantage in capturing water and light. In contrast, Carlson and Hill (1986) concluded that high N rates in wheat fields resulted in improved yields, when low densities of wild oat (*Avena fatua*) were present.

In spite of the various efforts in recent years to demonstrate the influence of plant nutrients on weed-crop mixtures, little research has been conducted to determine specific mechanisms of competition. Instead, studies have focused on quantifying yield changes at different fertility levels. The main reason for this occurrence seems to be that the type of studies required to determine the mechanism of competition is time-consuming and requires an in-depth knowledge of population dynamics. Nevertheless, studies in this regard can lead to new and improved fertilization strategies which might enhance crop competitiveness with weeds (DiTomaso 1995).

As indicated in the Okafor and DeDatta (1976) study, one possible consequence of nutrient competition is that availability of other resources can become limited further. In nutrient-rich situations and with low weed densities, crops are expected to perform better than in highly depleted environments. Studies about the interactive effects among essential factors requires more attention in weed science (Radosevich et al. 1997).

Phosphorus as a Competition Factor

Phosphorus Dynamics in the Soil Profile

Phosphorus (P) is an essential element for plant growth and development. This means that it is impossible for plants to complete their vegetative and/or reproductive cycle in the absence of this nutrient. Plants must obtain P from the soil in amounts necessary for survival. In most agricultural settings, P is provided in the form of fertilizer to ensure that appropriate amounts are supplied to crops, because native P is frequently not at sufficient levels (Brady 1990).

Soil P can be divided in two distinctive groups: a) inorganic and b) organic forms. Inorganic P is mostly found in mineral soils (less than 20% organic matter), whereas variable amounts of this element can be obtained in organic soils as it will be explained later. Most of the P found in mineral soils comes from the decomposition of the mineral apatite $[Ca_{10}(PO_4)_6(F,Cl,OH)_2]$ found in the Earth's crust. Fluorapatite, chlorapatite, hydroxyapatite; iron, aluminum, and calcium phosphates are some of the most frequent natural sources of P found in soils. However, other forms are obtained as phosphate reaction products after fertilizer applications. Some of these forms include dicalcium phosphate dihydrate ($CaHPO_4 \cdot 2H_2O$), anhydrous dicalcium phosphate ($CaHPO_4$), octocalcium phosphate $[Ca_4H(PO_4)_3 \cdot 3H_2O]$, calcium ferric phosphate $[CaFe_2(HPO_4)_4 \cdot 5H_2O]$, potassium and ammonium taranakite $[(K,NH_4)_3Al_5H_6(PO_4)_8 \cdot 18H_2O]$, acid potassium ferric phosphate, struvite, basic potassium ferric phosphate, and pyrophosphate products (Sample et al. 1980; Sanchez and Porter 1994).

In most cases, calcium phosphate $[Ca_2(HPO_4)_2]$ is a salt that is readily available to enter the plant in the soil solution. The solubility of the P forms shown above depends on their structure, the presence of other elements, the size of fertilizer particles, and the degree of hydration of the molecules. Plants absorb P primary as an orthophosphate ion $(H_2PO_4^-)$ or as secondary orthophosphate ion (HPO_4^{-2}). The absorption of one ion or another will depend upon pH. Under acidic conditions, $H_2PO_4^-$ absorption is favored, whereas in alkaline soils HPO_4^{-2} is preferentially taken up. Small amounts of pyrophosphate and metaphosphate may be used as well. However, since they may easily undergo hydrolysis, their absorption as such is limited (Brady 1990; Sample et al. 1980; Sanchez and Porter 1994).

The availability of P is a function of the amounts of Fe and Al oxides, Ca and Mg carbonate content, clay type and content, pH, water content, organic matter content, microbial activity, and temperature. These factors will determine the rates of mineralization and immobilization of P within the soil profile, as well as the relative amounts of water extractable P. In acidic soils, Fe and Al oxides can readily combine with phosphates to form insoluble Fe and Al phosphates. Oxide surfaces contain water molecules and hydroxide ions which are octahedrally coordinated with either Fe or Al. There is a direct relationship between the exchangeable Al found in soils and the extent of phosphate absorbed. Under alkaline conditions, precipitation of phosphate ions takes place by calcium carbonates to form insoluble dicalcium phosphate, hydroxyapatite and carbonatoapatite (Brady 1990; Sample et al. 1980; Sanchez and Porter 1994).

Another form of P immobilization occurs when Ca-saturated clays coordinate phosphate anions to their surfaces. It is been suggested that phosphate can replace hydroxyl groups from aluminum atoms. The latter process is more frequently found in 1:1 clays where hydroxyl groups are more exposed than in 2:1 clays. The former reaction probably takes place more in 2:1 clays where Ca saturation is greater compared to 1:1 aluminumsilicates (Brady 1990; Sample et al. 1980; Sanchez and Porter 1994).

Organic P forms are tightly linked to the presence of organic matter in soils, because of the different reaction products that can be obtained from organic material decomposition. These products could be divided into four groups: a) inositol phosphate (about 60%organic matter content), b) phospholipids (about 1%), c) nucleic acids (between 5 and 10%), and d) humic fraction (about 30 to 40%). Inositol phosphate is a cyclic, saturated 6-carbon ring with an alcohol group attached to each carbon. Phospholipids are represented by the presence of choline, a result of lecithin hydrolysis. Nucleic acids contain phosphoric acid within their structure. When these forms are mineralized, they are either taken up by microbial population, by plants, leached through the soil profile, or carried out to the labile pool of P. Humus can be important in retaining certain amounts of P based on its association with multivalent cations (Fe, Al, Ca) that could attract phosphate ions (Sample et al. 1980; Sanchez and Porter 1994).

Phosphatases, enzymes that are secreted by soil microbial population, hydrolyze complex organic molecules (mainly inositol phosphate) and release P into the soil solution. These enzymes can be extracellular or intracellular depending on the type of bacteria that is present. These organisms have enhanced activity under cultivated conditions as

compared to virgin soils. It is suspected that this increase in microbial activity is due to an increase in fertilization practices (Sample et al. 1980; Sanchez and Porter 1994).

Phosphorus in Histosols

Carbon:organic P ratio is an important indicator of how reactions are taking place in the soil. It is known that if this ratio is greater than 300, immobilization will occur, whereas ratios below 200 are indication of mineralization. The same appears to be true for C:inorganic P ratios (Sample et al. 1980; Sanchez and Porter 1994). It appears that enhanced microbial activity at high ratios is due to high amounts of electron donors for reactions, leading to organic matter breakdown. Temperature has an indirect effect on P processes, since there is an optimum range for enzymatic activity. Usually, warm temperatures (around 27°C) with cool nights (around 16°C) favor organic matter oxidation (Sample et al. 1980; Sanchez and Porter 1994).

Most organic P forms are present in Histosols of the EAA. However, as soil subsidence continues by oxidation of organic matter, carbonates ($CaCO_3$) from the underlying limestone can move upwards with high water tables or after heavy rainfall periods retaining P by the mechanisms discussed above. Also, amount of Fe and Al oxide could increase as oxidation and subsidence continue contributing to P retention. Since the vast majority of the soil profile in the EAA is covered by muck, it is unprovable to find significant amounts of native inorganic P from apatite minerals. Traditionally, these soils have been highly deficient in P with values of 2 to 5 mg/L of water extractable P, which is in most cases insufficient for commercial production. This occurrence justifies the use of P

fertilizers in the EAA (Sanchez and Porter 1994), and therefore competitive interactions between weeds and crops might take place.

Organic soils of the EAA are hydrologically linked to environmentally sensitive wetlands and to Lake Okeechobee (Sanchez et al. 1991). During the past few years, many research reports have indicated that drainage water loaded with P is contributing to the eutrophication of those water bodies and the degradation of the Water Conservation Areas and the Everglades National Park ecosystems (Izuno et al. 1991; Lynne et al. 1982). Cultural management practices leading to reduced P inputs in crops grown in Histosols of the EAA have to be studied (Windemuller et al. 1997). Banding P has shown to be a viable alternative to reduce the P fertilization rates in cabbage and sweet corn (Izuno et al. 1995; Sanchez et al. 1991).

Significance of Research

Lettuce is the most important leafy salad crop in the world. Weeds such as smooth pigweed and common purslane are ranked among the 15 most troublesome in the world (Holm et al. 1991). Their potential to reduce yields is due to their ability to interfere with lettuce for essential factors. Phosphorus, an essential plant nutrient, is naturally deficient in soils of the EAA requiring high inputs for satisfactory lettuce yields (Hochmuth et al. 1994). This element is relatively immobile in the soil profile. Therefore, a profuse rooting system is advantageous in order to assimilate P amounts required for plant growth and development.

Smooth pigweed and common purslane are known to have extensive underground structures that may enable these weeds to uptake P at the expense of lettuce. Thus, it is important to develop fertilization or crop production strategies that could enhance competitiveness of lettuce, minimize the impact of weeds, and reduce the P fertilization rates in soils of the EAA.

CHAPTER 3
RESPONSE OF VARIOUS WEEDS TO PHOSPHORUS RATES

Introduction

Many weeds occur in production areas of the Everglades Agricultural Area (EAA). Among those species that may interfere with lettuce production are smooth pigweed (*Amaranthus hybridus*), spiny amaranth (*A. spinosus*), common purslane (*Portulaca oleracea*), and barnyardgrass (*Echinochloa crus-galli*). The negative impact of these weeds may be due to their ability to capture water and essential nutrients from the soil at the expense of lettuce. At the same time, because these plants normally grow taller than lettuce, they may shade the crop reducing the amount of photosynthetic active radiation by the short-statured lettuce. Allelopathy is another source of weed interference that could cause lettuce yield reductions. These weeds may release organic compounds and/or root exudates into the soil that result in reduced growth of neighboring species.

Despite of our implicit knowledge about these possible sources of weed interference, few studies have focused on the effect of plant nutrients in weed-crop interactions (DiTomaso 1995). Among essential plant nutrients, phosphorus (P) is one of the most important for vital functions in plants. As described previously, many possible chemical and physical interactions with soil components limit P availability and mobility to plant roots. Species with profuse rooting systems could capture larger amounts of P. No

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information is available about the effect of different P rates on the growth and development of smooth pigweed, common purslane and barnyardgrass. Shrefler et al. (1994a) showed that spiny amaranth does not respond to P fertility. This species is closely related to smooth pigweed, thus it was included as point of reference. Consequently, the objective of these studies was to determine the P dose response of these weed species.

Materials and Methods

Greenhouse studies with barnyardgrass, smooth pigweed, spiny amaranth and common purslane were conducted from January to April 1996 in Gainesville, Florida. Two trials were carried out from January to February 1996 (referred thereafter as early spring trials) and from March to April 1996 (referred thereafter as late spring trials). During early spring trials, average day/night temperature, daylight and photosynthetic active radiation were 24/19°C, 12h and 1750 μmol·m^{-2}·sec^{-1}, respectively, whereas during late spring trials these values were 26/21°C, 13.5h and 1950 μmol·m^{-2}·sec^{-1}. Environmental conditions were recorded daily and averaged over time by using a conventional maximum/minimum thermometer, and a LI-COR LI-185 lightmeter equipped with a standard quantum sensor.

Plastic containers (approximately 7 L) were filled with screened Pahokee muck (Euic hyperthermic Lithic Medisaprist), low in P fertility as revealed by soil tests (water extractable P was 3.0 mg P L^{-1} of soil). Each weed species was directly seeded at densities of 1, 2, 4 and 7 plants per container (equivalent to 29, 58, 116 and 203 plants m^{-2}). Weed seeds were planted in excess and thinned after germination. A uniform spatial arrangement was utilized to provide each plant with the same soil volume. Five P rates (0, 0.25, 0.50,

1.00 and 2.00 g P L^{-1} of soil) were used. Ca(H$_2$PO$_4$)$_2$ was utilized as the P source. Measured P amounts were thoroughly mixed with the soil prior to planting. Other plant nutrients were provided at 7 and 21 days after planting with a non-P modified solution composed of 571 ppm NH$_4$NO$_3$, 777 ppm KNO$_3$, 555 ppm CaCl$_2$, 250 ppm MgSO$_4$, 24 ppm FeSO$_4$·7H$_2$O, 1.80 ppm MnCl$_2$·4H$_2$O, 2.82 ppm H$_3$BO$_3$, 0.22 ppm ZnSO$_4$·7H$_2$O, 0.08 ppm CuSO$_4$·5H$_2$O, and 0.02 ppm MoO$_3$, dissolved in 1 L of deionized water. Drip irrigation was utilized to maintain the soil at field capacity by providing 1 L of water three times per day. In both seasons, plants were harvested 30 days after planting and shoot dry weight was collected after drying samples for 6 days at 70^{0}C in a air-forced oven. Phosphorus (P) tissue content in the shoots harvested was performed by using the colorimetrically method of Murphy and Riley (1962).

A 5 x 4 factorial experiment in a split-plot design with 4 replications was established during each season, where P rates were main plots and weed density comprised subplots. Analysis of variance (ANOVA) was performed to determine significant (P=0.05) treatment effects and interactions. Regression analysis was performed to characterize possible dependencies between P rate and shoot dry weight. Treatment means were separated by standard errors.

Results and Discussion

Shoot Dry Weight

No significant treatment by season interactions (P>0.05) were found for shoot dry weight per plant in all weed species tested. Therefore, data from early and late spring trials

were combined. Barnyardgrass and common purslane showed significant P by density interactions (P<0.05) for shoot dry weight per plant, whereas smooth pigweed and spiny amaranth did not.

Barnyardgrass density and P rate interactively influenced shoot dry weight per plant. At 1 plant per container, barnyardgrass had maximum shoot dry weight per plant when P supplied was between 0.25 and 1 g L^{-1} soil, declining afterwards (Table 3-1). Shoot dry weight increased 2.7 times when P increased from 0 to 0.25 g P L^{-1} soil. At this density a quadratic equation described the relationship between P applied and shoot dry matter produced per plant. Phosphorus had no impact on shoot dry weight at higher densities. The amount of P provided was enough to produce a positive response on barnyardgrass biomass accumulation at a density of 1 plant per container, suggesting that high intraspecific competition for P may have occurred at higher densities.

Smooth pigweed and spiny amaranth shoot dry weights were not affected by P rate (Tables 3-2 and 3-3). However, plant density had an effect on biomass accumulation. Maximum shoot dry biomass accumulation occurred with 1 plant per container, with an average weight of 3.02 and 2.11 g per plant for smooth pigweed and spiny amaranth, respectively. These findings agree with those reported by Shrefler et al. (1994a), where spiny amaranth dry matter accumulation did not respond to increased P fertility. A related species, smooth pigweed, showed no biomass increase with increasing P rates, indicating that the P amounts naturally occurring in the soil (3.0 mg P L^{-1} of soil) are sufficient to satisfy the nutritional demand for this element of these two weed species.

Table 3-1. Effect of phosphorus (P) rates on barnyardgrass shoot dry weight per plant.

P rate	Density			
	----------------------plants container^{-1}----------------------			
g L^{-1} soil	1	2	4	7
0	2.80±0.2	4.01±0.8	1.52±0.5	0.70±0.2
0.25	7.50±0.7	5.25±0.7	1.75±0.4	0.72±0.3
0.5	7.55±0.5	4.75±0.5	2.25±0.6	0.71±0.1
1	7.55±0.6	4.52±0.6	2.03±0.6	0.72±0.2
2	4.00±0.5	4.25±0.7	2.01±0.5	0.71±0.3

Note: Quadratic equation for barnyardgrass shoot dry weight per plant at a population density of 1 plant per container was $y = 3.93 + 9.04x - 4.55x^2$; $r^2=0.88$.

Table 3-2. Effect of population densities on smooth pigweed shoot dry weight per plant.

Density	Shoot dry weight per plant
plants container^{-1}	-----------------g-----------------
1	3.02±0.51
2	1.64±0.80
4	0.79±0.08
7	0.39±0.06

Note: Linear equation for smooth pigweed shoot dry weight per plant averaged within each population density was y = 2.84 - 0.39x; r^2=0.89.

Table 3-3. Effect of population densities on spiny amaranth shoot dry weight per plant.

Density	Shoot dry weight per plant
plants container^{-1}	----------------g------------------
1	2.11±0.43
2	1.20±0.20
4	0.41±0.10
7	0.38±0.05

Note: Linear equation for spiny amaranth shoot dry weight per plant averaged within each population density was y = 1.94 - 0.26x; r^2=0.85.

Common purslane density and P rate interactively influenced shoot dry weight per plant (Figure 3-1). Two distinctive P response patterns were observed. On one hand, 1 and 2 plants per container followed the same trend according to a logarithmic equation. On the other hand, another logarithmic regression characterized the P rate-shoot dry weight per plant relationships of 4 and 7 plants per container. As shown in Figure 3-1, maximum shoot dry weight values were found between 0.50 and 1.00 g P L^{-1} soil with either 1 or 2 common purslane plants per container. A dramatic increase in this variable was measured when P rate changed from 0 to 0.50 g P L^{-1} soil, representing approximately a 3 fold increment.

Phosphorus Tissue Content

Phosphorus tissue content analysis for smooth pigweed and common purslane revealed that these two species followed two very distinctive patterns in terms of P rate response. While neither P rate nor density affected ($P>0.05$) smooth pigweed P tissue content, both factors interactively ($P<0.05$) influenced common purslane P tissue content (Figure 3-2).

No significant regression equation was found for smooth pigweed, showing that P tissue content was not a function of P rate, averaging approximately 0.40% of total shoot dry weight. On the other hand, common purslane P tissue content was significantly influenced by P rate. Two positive logarithmic equations characterized the response of this weed to P rate, one for 1 and 2 plants per container and another for 4 and 7 plants per container. Maximum P content values were measured when P rate was greater than 0.50 g P L^{-1} soil for all densities. Phosphorus content was 2.5 and 2.2 times higher than the
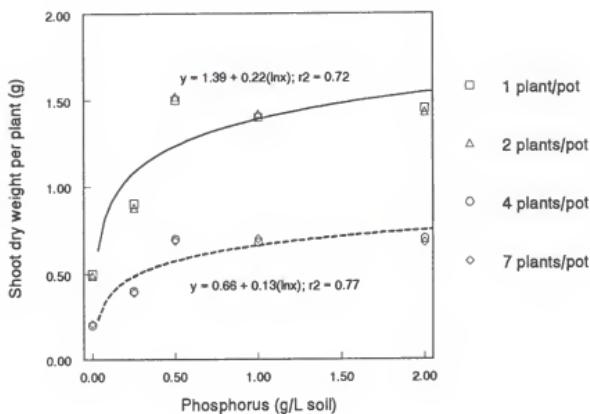
Figure 3-1. Effect of phosphorus (P) rates on common purslane shoot dry weight.
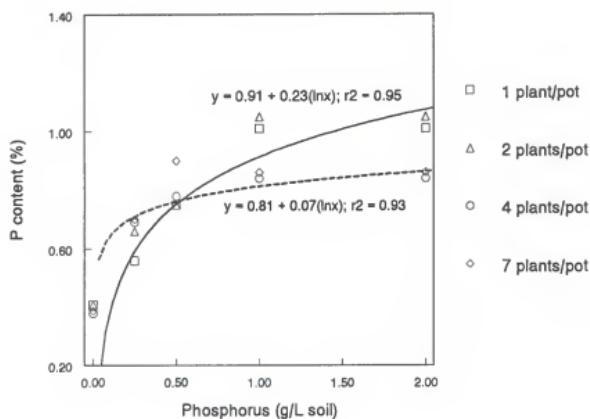
Figure 3-2. Effect of phosphorus (P) rates on common purslane P tissue content.

control. Common purslane intraspecific competition for P seemed to be greater as density increased, since P percentages decreased at the highest two densities as P rate approached 1 g P L^{-1} soil.

Conclusions

Due to the narrow range of response to P rates by barnyardgrass, common purslane appeared to be a more suitable species for subsequent trials on the effect of weed density and P fertility on lettuce growth and yield, because different responses in terms of density and P rate were found. On the other hand, smooth pigweed and spiny amaranth, two related species of the genus *Amaranthus*, showed no P effect on biomass as P rates were applied. Previous studies with spiny amaranth showed that the negative impact caused by the weed on lettuce could be reduced by altering the method of P application (Shrefler 1994b).

In order to fulfill the objectives of the studies, common purslane and smooth pigweed were chosen as target species. These two weeds represent two contrasting situations encountered in lettuce fields in terms of P fertility as an interference factor.

CHAPTER 4
INTRASPECIFIC AND INTERSPECIFIC INTERFERENCE OF
SMOOTH PIGWEED AND COMMON PURSLANE WITH LETTUCE
AS AFFECTED BY PHOSPHORUS RATES

Introduction

Intensive pest management is a key component in the commercial production of most leafy vegetables, including lettuce. Weed management represents a large share of the cost of growing high quality lettuce. Most of the crisphead lettuce produced in the state of Florida is planted on the organic soils (>70% organic matter) of the Everglades Agricultural Area (EAA), where hoeing and cultivation are currently the main methods for weed control. These weed control methods are costly and result in disturbance of the lettuce rooting system. Smooth pigweed and common purslane are two of the most troublesome weeds found in lettuce grown on the organic soils of South Florida. These weeds have profuse rooting systems and are difficult to control due to their rapid growth rate and ability to resprout from cuttings produced by hoeing and/or cultivation.

Phosphorus (P), an essential plant nutrient, is naturally deficient in soils of the EAA requiring high inputs for satisfactory lettuce yields (Hochmuth et al. 1994). Labile phosphates released into these organic soils are immobilized by microorganisms, absorbed by plants or lost by leaching. Because, P is a relatively immobile nutrient in the soil profile (Sample et al. 1980), a profuse rooting system is advantageous to capture P amounts

required for plant growth and development. The influence of this nutrient on the competitive interactions of smooth pigweed and common purslane in lettuce fields has not been reported. Shrefler et al. (1994a) determined that the competitive ability of lettuce can be enhanced by providing high P rates to organic soils in spiny amaranth (*Amaranthus spinosus*)-lettuce complexes.

In studying competitive interactions among species, replacement series are frequently used to describe the relationships between 2 species under a given set of conditions (Jolliffe et al. 1984; Radosevich 1987; Roush et al. 1989). Varying plant proportions are used within densities to determine the relative competitiveness of two species (Cousens 1991; de Wit 1960). Relative yield is calculated to interpret competitiveness of each species (Rejmanek et al. 1989). An increase in this variable suggests enhanced competitive ability by that species. The objective of this research was to determine the effect of P application rates and plant population densities on the competitiveness of smooth pigweed and common purslane with lettuce.

The null hypotheses to test in this study were:

a) There are no intraspecific and interspecific competitive interactions between smooth pigweed and lettuce, and

b) There are no intraspecific and interspecific competitive interactions between common purslane and lettuce.

The overall objectives of this study were as follows: a) determine the effect of P fertility rates and population densities on the competitive interactions of smooth pigweed

with lettuce, and b) determine the effect of P fertility rates and population densities on the competitive interactions of common purslane with lettuce.

Materials and Methods

Studies were conducted from May to September 1996 in Gainesville, Florida. Lettuce-smooth pigweed and lettuce-common purslane competition studies were conducted under greenhouse conditions. Average temperature, daylength and photosynthetic active radiation were 29/24°C, 14 h, and 2050 μmol·m^{-2}·sec^{-1}, respectively. Environmental conditions were monitored daily and averaged over time by using a conventional maximum/minimum thermometer, and a LI-COR LI-185 lightmeter equipped with a standard quantum sensor.

Plastic containers (2.4 L) were filled with screened Pahokee muck (Euic hyperthermic Lithic Medisaprist), which was low in P for optimum lettuce yields as revealed by soil tests (water extractable P of 3.0 mg P L^{-1} of soil). Rates of P used were 0, 0.4 and 0.8 g of P L^{-1} of soil (referred hereafter as low, medium and high P, respectively), using $Ca(H_2PO_4)_2$ as the P source. Amounts of P were added to each container and thoroughly mixed one week prior to planting. Nutrients, other than P, were provided 7 and 21 days after planting with a non-P modified nutrient solution composed of 571 ppm NH_4NO_3, 777 ppm KNO_3, 555 ppm $CaCl_2$, 250 ppm $MgSO_4$, 24 ppm $FeSO_4·7H_2O$, 1.80 ppm $MnCl_2·4H_2O$, 2.82 ppm H_3BO_3, 0.22 ppm $ZnSO_4·7H_2O$, 0.08 ppm $CuSO_4·5H_2O$, and 0.02 ppm MoO_3, dissolved in 1 L of deionized water. Drip irrigation was utilized to maintain the soil at field capacity by providing 1 L of water three times per day.

Seeds of either weed and 'South Bay' lettuce were sown in the containers. Plants were thinned 3 days after emergence to the desired densities. A uniform spatial arrangement within each container was used to allow each plant to have the same growing area. A replacement series study was used with total densities of 2, 4 and 8 plants per 113 cm^2 (referred hereafter as low, medium and high density, respectively), equivalent to 177, 354 and 708 plants m^{-2}. Monocultures of lettuce and each weed species were established along with 50:50 mixtures, where the first number of the ratio indicates lettuce and the second the weed. Four replications of each treatment were established within a randomized complete block design. The study was repeated.

Plants were allowed to compete for 35 days before shoots were harvested and dried at 70ºC for 5 days for dry weight determination. Shoot dry weight per plant was determined and samples were stored in air-tight plastic bags for analysis of total shoot P content per plant, which was determined using the colorimetric method by Murphy and Riley (1962). Relative yield (RY) was calculated for each species involved within each P rate utilized by using the equation 4-1:

$$RY = W_{mix}/W_{mono} \qquad [4\text{-}1]$$

where W_{mix} and W_{mono} represent the shoot dry weight per container of the species involved in mixture and in monoculture, respectively. This variable was calculated for each density and proportion.

Treatments were arranged in 3 x 3 x 3 factorial experiment for each weed-lettuce complex within a split-split-plot design with four replications, where P rates were main plots, densities comprised subplots, and proportions sub-subplots. Two trials were conducted and measured data sets were subjected to analysis of variance (ANOVA) to test for significant treatment effects at the 5% significance level. Since no significant interactions (P=0.05) between trials and treatments were observed, the data from the two trials were combined. If significant differences among treatments were found, treatment means were compared using standard errors. Regression analysis was performed to characterize the relationship between density and shoot dry weight per plant and RY for each P rate applied.

Results and Discussion

Smooth Pigweed-Lettuce Studies

Density and P rate interactively (P<0.05) influenced lettuce shoot dry weight per plant, where as only density affected smooth pigweed shoot dry weight (Figure 4-1). Shoot dry weight per plant in monocultures of smooth pigweed and lettuce decreased with density. Linear regression equations characterized the shoot dry weight per plant responses as affected by density. Smooth pigweed was not responsive to P rates, therefore values were averaged for three P rates as a function of density (Figure 4-1). As P rate increased, there was an increase in lettuce biomass production per plant in the 100:0 proportion. These equations show that monocultures of lettuce at the lowest P level and smooth pigweed monocultures had the same slope, indicating that reductions in shoot dry
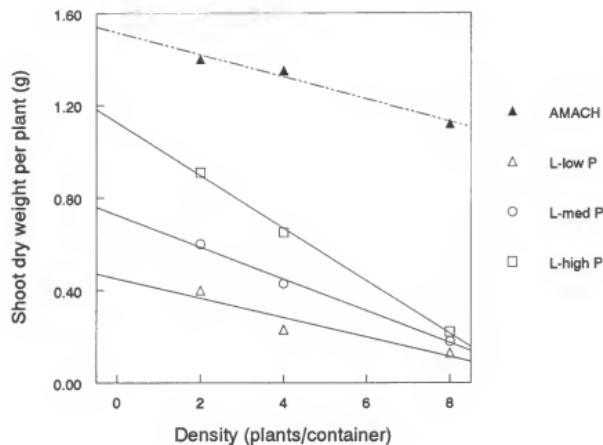
Figure 4-1. Shoot dry weight per plant (W) of lettuce (L) and smooth pigweed (AMACH) as affected by density (D). Regression equations are $W = 1.52 - 0.05D$, $r^2 = 0.98$ for smooth pigweed averaged over P rates; $W = 0.45 - 0.05D$, $r^2 = 0.94$ for lettuce at a P rate of 0 g L^{-1} soil (low P); $W = 0.73 - 0.07D$, $r^2 = 0.98$ for lettuce at a P rate of 0.4 g L^{-1} soil (med P); and $W = 1.13 - 0.11D$, $r^2 = 0.97$ for lettuce at a P rate of 0.8 g L^{-1} soil (high P).

weight per plant followed the same rate. However, as P rate increased in monocultures, lettuce biomass production declined more rapidly, suggesting stronger intraspecific competition at higher P rates.

Relative yield analysis for the 50:50 proportion revealed that density and P rate independently had an influence on lettuce competitiveness, whereas only density affected smooth pigweed (Figure 4-2). Lettuce competitive ability increased with increasing P rate, but decreased with increased density. Parallel linear regression equations described the relationships between density and lettuce. In all cases, smooth pigweed was more competitive than lettuce as revealed by the regression equations.

Lettuce and smooth pigweed total shoot P content was influenced on a per plant basis by density and P rate applied in both monocultures and 50:50 mixtures (Table 4-1). At the 100:0 proportion, lettuce P content increased with increased P rate and decreased with increased density. Highest P content values were observed at the highest P rate and at the lowest density. When grown in 50:50 mixtures, lettuce shoot P content values were significantly lower for each treatment, indicating that smooth pigweed had a negative impact on the acquisition of this element from the soil by lettuce plants in comparison to lettuce grown alone.

Smooth pigweed shoot P content increased with increased P rate and decreased with increased density. When grown in 50:50 mixtures, P content increased compared to the weed grown in monoculture. Because no increases in smooth pigweed shoot dry weight per plant were observed as P rate increased, luxurious P consumption may be occurring. Shrefler et al. (1994a) drew comparable conclusions when dealing with spiny
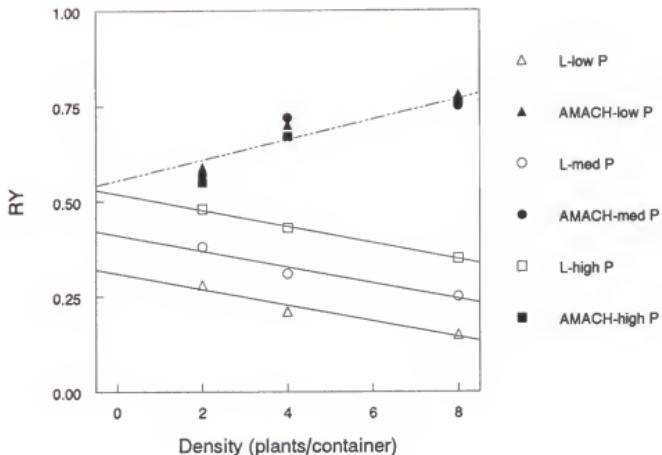
Figure 4-2. Relative yield (RY) of lettuce (L) and smooth pigweed (AMACH) as affected by density (D). Regression equations are $RY = 0.56 + 0.03D$, $r^2 = 0.85$ for smooth pigweed averaged over P rates; $RY = 0.31 - 0.02D$, $r^2 = 0.97$ for lettuce at a P rate of 0 g L^{-1} soil (low P); $RY = 0.41 - 0.02D$, $r^2 = 0.97$ for lettuce at a P rate of 0.4 g L^{-1} soil (med P); $RY = 0.51 - 0.02D$, $r^2 = 0.98$ for lettuce at a P rate of 0.8 g L^{-1} soil (high P).

Table 4-1. Effect of density and phosphorus (P) rate on lettuce and smooth pigweed total shoot P content per plant in monocultures and 50:50 mixtures.

	Density (plants container^{-1})			Density (plants container^{-1})		
	2	4	8	2	4	8
P Rate[c]	Lettuce (100:0)			Lettuce (50:50)		
g L^{-1} soil	------------------------------------mg plant^{-1}------------------------------------					
0	2.0±0.21	0.9±0.05	0.4±0.02	1.3±0.08	0.4±0.01	0.2±0.01
0.4	3.6±0.12	2.2±0.12	0.8±0.04	2.1±0.11	1.5±0.08	0.4±0.02
0.8	6.4±0.22	3.9±0.18	1.2±0.09	4.8±0.13	2.1±0.15	0.9±0.05
	Pigweed (0:100)			Pigweed (50:50)		
0	2.1±0.19	0.8±0.04	0.4±0.01	3.0±0.18	1.5±0.07	0.8±0.07
0.4	7.1±0.22	6.2±0.33	3.5±0.23	16.2±0.41	12.3±0.80	3.5±0.21
0.8	14.3±0.31	12.8±0.50	8.6±0.33	28.4±0.38	23.5±0.56	8.9±0.35

Note: Data are means for 2 experiments combined. Plants were grown for 35 days.

amaranth and lettuce under varying P rates. It seems that the extensive rooting system of smooth pigweed enables the weed to absorb P at the expense of lettuce roots, depriving the crop from quantities of P that otherwise would be available for lettuce uptake. Higher P rates appear to counteract the negative impact of smooth pigweed on lettuce P acquisition. Although P absorption seems to be one mechanism of interference in smooth pigweed-lettuce complexes under the conditions of this experiment, competition for other essential factors (i.e. light) may play a role in lettuce-smooth pigweed interactions. Additional research should be conducted to establish the primary mechanism of interference of this weed on lettuce. In practical terms, manipulation of P fertilization method may be a viable alternative to reduce smooth pigweed interference by concentrating this nutrient closer to the lettuce rooting system (i.e. banded applications), giving the crop a competitive edge against the weed.

Common Purslane-Lettuce Studies

Common purslane shoot dry weight per plant in monocultures were independently ($P<0.05$) influenced by density and P rate (Figure 4-3), whereas density and P rate interactively ($P<0.05$) affected lettuce shoot dry weight. Lettuce monocultures followed the same patterns discussed in the smooth pigweed-lettuce studies. Common purslane shoot dry weight per plant decreased with increasing density and increased with increasing P rate. Parallel linear regression equations characterized the shoot dry weight per plant responses for the weed as affected by density. The equal slopes of the regression equations indicate that increasing density had the same adverse impact on shoot dry weight
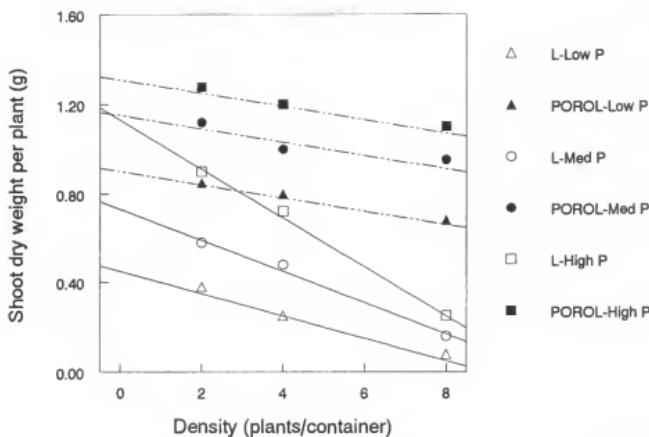
Figure 4-3. Shoot dry weight per plant (W) of lettuce (L) and common purslane (POROL) as affected by density (D). Regression equations are W = 0.90 - 0.03D, r^2 = 0.98 for purslane at a P rate of 0 g L^{-1} soil (low P); W = 1.15 - 0.03D, r^2 = 0.96 for purslane at a P rate of 0.4 g L^{-1} soil (med P); W = 1.31 - 0.03D, r^2 = 0.97 for purslane at a P rate of 0.8 g L^{-1} soil (high P); W = 0.45 - 0.05D, r^2 = 0.94 for lettuce at a P rate of 0 g L^{-1} soil (low P); W = 0.73 - 0.07D, r^2 = 0.98 for lettuce at a P rate of 0.4 g L^{-1} soil (med P); and W = 1.13 - 0.11D, r^2 = 0.97 for lettuce at a P rate of 0.8 g L^{-1} soil (high P).

regardless of the P rate utilized in monocultures of common purslane, suggesting equal intraspecific competition at all P rates.

Linear regression equations characterized the response of RY with respect to density for common purslane and lettuce mixtures. Common purslane competitiveness was enhanced by higher P rates, where as lettuce competitive ability remained unchanged (Figure 4-4). Parallel linear equations described density by RY relationships. For all P rates, common purslane was the strongest competitor in 50:50 mixtures with lettuce regardless of P rate.

Lettuce and common purslane total shoot P content was influenced on a per plant basis by density and P rate in both monocultures and 50:50 mixtures (Table 4-2). In lettuce monocultures, P content followed the same pattern showed in smooth pigweed-lettuce studies, where P content was diminished by density and enhanced by P rate. In lettuce-common purslane mixtures, the weed accumulated more P than in pure weed monocultures, indicating that the weed absorbed more P when competing against lettuce than when competing against itself.

Based on the data discussed herein, P competition plays a significant role in the interactions between lettuce and common purslane. Phosphorus competition seems to be the main mechanism of interference of this weed on lettuce. Additional studies have to be conducted to determine whether other essential factors might be influencing lettuce response and competitiveness. In field situations, where P is applied broadcast higher P
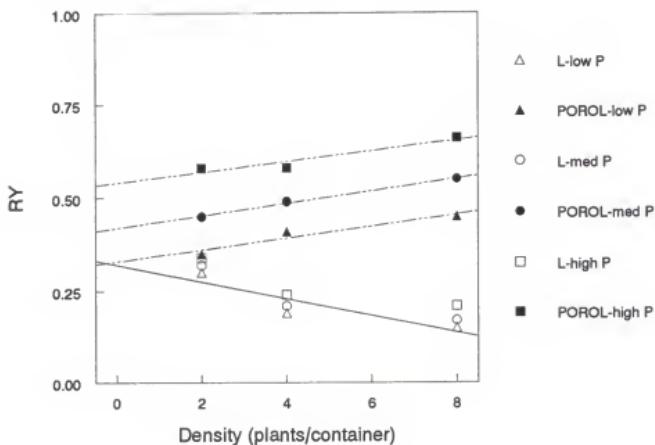
Figure 4-4. Relative yield (RY) of lettuce (L) and common purslane (POROL) as affected by density (D). Regression equations are RY = 0.32 - 0.02D, r^2 = 0.89 for lettuce averaged over P rates; RY = 0.33 + 0.02D, r^2 = 0.95 for lettuce at a P rate of 0 g L^{-1} soil (low P); RY = 0.42 + 0.02D, r^2 = 0.97 for lettuce at a P rate of 0.4 g L^{-1} soil (med P); RY = 0.54 + 0.02D, r^2 = 0.94 for lettuce at a P rate of 0.8 g L^{-1} soil (high P).

Table 4-2. Effect of density and phosphorus (P) rate on lettuce and common purslane total shoot P content per plant in monocultures and 50:50 mixtures.

	Density (plants container^{-1})			Density (plants container^{-1})		
	2	4	8	2	4	8
P Rate^{c}	Lettuce (100:0)			Lettuce (50:50)		
g L^{-1} soil	------------------------------mg plant^{-1}------------------------------					
0	2.0±0.21	0.9±0.05	0.4±0.02	0.6±0.10	0.3±0.02	0.1±0.01
0.4	3.6±0.12	2.2±0.12	0.8±0.04	1.7±0.21	0.9±0.10	0.3±0.05
0.8	6.4±0.22	3.9±0.18	1.2±0.09	3.2±0.22	1.7±0.12	0.7±0.07
	Purslane (0:100)			Purslane (50:50)		
0	2.2±0.28	1.0±0.07	0.6±0.04	3.0±0.17	1.8±0.10	1.0±0.05
0.4	8.2±0.30	7.3±0.32	4.3±0.19	21.5±0.50	18.7±0.92	14.3±0.28
0.8	19.7±0.50	15.8±0.33	11.3±0.55	39.6±0.67	33.5±0.45	25.3±0.33

Note: Data are means for 2 experiments combined. Plants were grown for 35 days.

rates may benefit common purslane more than lettuce. Therefore, alternative fertilizer management strategies need to be developed to reduce the impact of this weed on the crop.

Conclusions

The analysis of the data collected from this study led to the rejection of the null hypotheses, and to the acceptance of the alternative hypotheses that a) there were significant interspecific and intraspecific competitive interactions between smooth pigweed and lettuce, and b) there were significant interspecific and intraspecific competitive interactions between common purslane and lettuce.

In smooth pigweed-lettuce interference complexes, lettuce competitive ability can be modified by P rates provided. As P increased, lettuce competitive ability was enhanced without increasing smooth pigweed competitiveness, emphasizing the necessity of appropriate P fertility for enhanced lettuce biomass accumulation. At the same time, P tissue content of smooth pigweed increased with increasing P rates with no significant shoot biomass enhancement. Luxurious P consumption by smooth pigweed could be a possible explanation. Shrefler et al. (1994a) reported similar results with spiny amaranth, a related species to smooth pigweed with a similar extensive rooting system that may enable these species to capture P at the expense of lettuce plants.

In common purslane-lettuce complexes, the weed appeared to benefit more with increasing P rate in the system at the expense of lettuce absorption. This illustrates the potential negative impact that this weed could cause in lettuce stands, since it enhanced its competitiveness with lettuce in a P-rich environment under the conditions of these studies.

It may be reasonable to expect than under high P fertility situations, common purslane will benefit for two reasons: a) increased lettuce intraspecific competition at high densities, and b) its profuse rooting system being able to intercept and absorb P from the common soil pool depriving lettuce of this essential nutrient. In relative terms, common purslane may have a much more pronounced negative impact on lettuce production than smooth pigweed, since the competitive ability of lettuce against smooth pigweed can be enhanced by increasing P supply, whereas little or no change in lettuce aggressiveness could be observed with common purslane under the same P conditions.

The data discussed above helps provide insight into the potential interactions that may occur under field conditions, and how an essential factor such as P can affect these relationships. In practical terms, the manipulation of P amounts provided to lettuce could be a viable alternative to counteract the interference of smooth pigweed on the crop stands. On the other hand, banded P applications might be advantageous to lettuce to give the crop a competitive advantage against common purslane, by concentrating this nutrient closer to the lettuce rhizosphere and, giving the crop a higher opportunity to absorb P. Further studies will be conducted to determine whether P placement has a role in the competition of these weeds and lettuce.

CHAPTER 5
EFFECTS OF SMOOTH PIGWEED AND COMMON PURSLANE
DENSITIES ON LETTUCE YIELDS UNDER DIFFERENT
PHOSPHORUS FERTILITY REGIMES

Introduction

Lettuce (*Lactuca sativa* L.) is the leading leafy vegetable crop in terms of acreage planted and value in the U.S. (Dusky and Stall 1995). Major lettuce production areas in Florida are concentrated in the organic soils (50-80% organic matter) of the Everglades Agricultural Area (EAA) and around Lake Apopka. Among the many pests that occur in lettuce fields, weeds can cause significant losses in yield and quality. Traditionally, hoeing and cultivation have been used for weed control in lettuce. These methods are costly and time consuming for farmers. At the same time, these mechanical procedures can cause significant damage to the shallow rooting system of the crop.

Currently, few herbicides are registered for weed management in lettuce produced on organic soils. The cost of herbicide registration along with environmental concerns about herbicide carry-over and movement to ground water justify the search for alternative weed management strategies. A key component within these alternative methods is the use of cultural means within an overall weed management program. Cultural weed control implies the use of crop rotation and enhanced crop competitiveness against weeds for essential factors such as light, water, and nutrients (Anderson 1983).

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However, to develop effective cultural weed management techniques, research needs to be conducted to better understand crop-weed interactions. For example, little is known about the relationship between weed density and crop yields (McWhorter and Shaw 1982).

Usually, competition for nutrients is not independent of competition for other resources, affecting also the balance for water and light (DiTomaso 1995). Several reports have emphasized the influence that nitrogen fertility has on providing an additional advantage to weeds or crops (Carlson and Hill 1986; Okafor and DeDatta 1976). However, scarce information is available about phosphorus (P) influence on leafy vegetable competitiveness. Sanchez et al. (1991) demonstrated that higher sweet corn (*Zea mays* L.) yield can be obtained by banding 33% of the recommended broadcast P amount compared to broadcast P treatments. Shrefler et al. (1994b) showed that banding P beneath lettuce rows provided a competitive edge to the crop against spiny amaranth (*Amaranthus spinosus* L.) interference. In the preceding chapter, it was shown that P manipulation can be a potential tool for changing the competitive balance in favor of lettuce. Research has not been conducted to determine the impact of different P fertility regimes on lettuce-smooth pigweed and lettuce-common purslane interactions.

Phosphorus fertility is a key component of lettuce production in the EAA, since these soils are naturally deficient of this element (Hochmuth et al. 1994). In addition, P is a relatively immobile nutrient in the soil profile (Sample et al. 1980). Therefore, plants with large root volume, such as smooth pigweed and common purslane, may capture P more efficiently than lettuce.

The null hypotheses to test in this study were:

a) Phosphorus placement has no influence on the yield reductions caused by smooth pigweed on lettuce grown under field conditions, and

b) Phosphorus placement has no influence on the yield reductions caused by common purslane on lettuce grown under field conditions.

The specific objectives to accomplish were a) to determine the extent of yield reductions caused by smooth pigweed densities on lettuce as affected by two P fertility regimes, and b) to determine the extent of yield reductions caused by common purslane densites on lettuce as affected by two P fertility regimes.

Materials and Methods

Lettuce-smooth pigweed and lettuce-common purslane competition studies were conducted at the Everglades Research and Education Center of the University of Florida in Belle Glade. Two trials were conducted from October 1996 to January 1997, and from September to December 1997. Soil type was a Pahokee muck (Euic hyperthermic Lithic Medisaprist) with a organic matter content of approximately 75% and pH of 6.3. Average day/night temperatures were 28/17°C. Water-extractable P was 3.0 mg P L^{-1} of soil, which is insufficient for commercial lettuce production (Hochmuth et al. 1994; Sanchez et al. 1990). Phosphorus was either broadcast (250 kg·ha^{-1} P) or banded (125 kg·ha^{-1} P) two to five cm beneath each lettuce row. Ca(H$_2$PO$_4$)$_2$ was utilized as the P source for broadcast treatments, while phosphoric acid was used in banded treatments. These rates were

provided for maximum crop yield (Sanchez et al. 1990). Other plant nutrients were applied broadcast following soil analysis and recommendations.

Crisphead lettuce (cv. South Bay) was direct-seeded in rows on top of 0.9-m planting beds with two rows per bed (30 cm in-row and between row spacing). Seeds of smooth pigweed and common purslane were germinated in multiple cell trays (24 cm^3 cell^{-1}) 10 days before lettuce planting. At lettuce emergence, weed seedlings in the two-true leaf stage were transplanted between the two lettuce rows at the following densities: 0, 2, 4, 8, or 16 plants per 6 m of row (5.4 m^2), equivalent to 0, 0.37, 0.75, 1.50, and 3.00 plants per m^2. Undesirable weeds were removed by hand and/or hoeing. Lettuce rows were thinned to a distance of approximately 30 cm between plants.

Treatments were factorially arranged with two P fertility regimes, two weed species, five weed densities, and four replications within a split-plot design, where P fertility regimes were main plots and weed densities were subplots. The central 50% of the surface area of each experimental unit was harvested when lettuce plants in weed-free controls reached maturity based on head firmness, size, and appearance. Outermost wrapper leaves were removed at harvest time. Marketable lettuce head number, head fresh weight, butt width, core length and head diameter were measured at harvest. Butt width, core length and head diameter were measured to determine lettuce head quality. Based on current lettuce market standards, loose heads with excessively long (>7.5 cm) stem cores and wide butts are not desirable for marketing purposes (USDA 1985).

Data collected were subjected to analysis of variance (ANOVA) to test for single factor effects and interactions (SAS Inst. 1987). No significant interactions (P>0.05)

between the two trials and the treatments were observed, consequently data was pooled. Treatment means were separated by standard errors calculated from the resulting data for each variable.

Results and Discussion

Smooth Pigweed-Lettuce Studies

There were significant interactions (P<0.05) between P fertility regime and density on marketable lettuce fresh weight, butt width, core length and head diameter (Figures 5-1, 5-3, 5-5, 5-7 and 5-9). Marketable lettuce head number per treatment was not affected (P>0.05) by either factor. In all cases, marketable fresh weight was greater when P was banded than when broadcast, including the weed-free control. Lettuce fresh weight tended to decrease as density increased within each P regime (Figure 5-1). However, P fertility regime differentially impacted the critical smooth pigweed density with respect to lettuce head fresh weight. With broadcast P, significant yield reductions were observed between densities of 2 and 4 smooth pigweed plants per 6 m of row, equivalent to approximately 20%. When P was banded, lettuce yield reductions occurred between 8 and 16 plants per 6 m of row, representing an average 24% decrease. Since lettuce head number was not affected, the effect of the weed on lettuce was due to reduction of fresh and dry weight accumulation on a per head basis.

Values for butt width, core length and head diameter are indicators or lettuce quality (USDA 1985). For all these quality indicators, higher values were observed in banded P treatments compared to broadcast P. In weed-free situations, butt width, core

length and head diameter showed 9, 10 and 3% increases when P was applied banded compared with broadcast (Figures 5-5, 5-7 and 5-9). Smooth pigweed densities of 8 plants per 6 m of row or less failed to reduce butt width and core length in banded treatments, whereas a density of more than 2 plants per 6 m of row caused a 3% decrease in head diameter compared with the weed-free control. In broadcast treatments, a weed density of more than 2 plants per 6 m of row resulted in butt width, core length and head diameter of 22, 12 and 4%. Although an increase in butt width and core length is not desirable within certain market standards (USDA 1985), the decrease in these variables as weed density increased probably corresponded to a significant decrease in the size of the lettuce heads. The butt width and core length values observed for either banded P with 0, 2, 4 and 8 smooth pigweed plants, or for broadcast treatments with 0 and 2 weeds, are considered within normal range for market standards.

Common Purslane-Lettuce Studies

Phosphorus fertility and weed density independently (P<0.05) influenced lettuce marketable fresh weight, butt width, core length and head diameter (Figures 5-2, 5-6, 5-8 and 5-10). Number of marketable heads per treatment was not affected by either factor (Figure 5-4). There were differences in lettuce fresh weight when P was banded compared to broadcast P within each common purslane density. There was about a 13% increase in lettuce fresh weight with banded P compared to broadcast P. In all cases, lettuce fresh weight decreased as weed density increased. Maximum yield reductions of 48 and 44% occurred with 16 common purslane plants per 6 m of row for broadcast and banded P, respectively.

Quality indicators such as butt width, core length and head diameter followed similar trends to those observed for head fresh weight (Figures 5-6, 5-8 and 5-10). Banded P treatments resulted in higher values for all these variables. In the absence of weed interference, banded P resulted in increases of 7, 6 and 3% in butt width, core length and head diameter, respectively, compared with broadcast applications. In all cases, the critical density to result in significant change in these variables remained between 0 and 2 common purslane plants per 6 m of row. At the highest weed density when P was broadcast, lettuce butt width, core length and head diameter declined 25, 25 and 4%, respectively, compared with the weed-free control. With banded P, reductions of 24, 18 and 6% were measured at the highest weed density for these quality variables. As described previously, wide basal butts and long stem cores are not desirable properties in lettuce heads. Under the conditions of these studies, the decrease in these variables as weed density increased most likely resulted from a significant decrease in the size of the lettuce heads.

Contrary to smooth pigweed, where critical densities varied as P regimes was manipulated, common purslane critical density remained between 0 and 2 plants per 6 m of row, resulting in 16 and 17% declines in lettuce fresh weight for banded and broadcast P, respectively. However, banding seemed to allow lettuce plants to utilize and capture P better by placing and concentrating P closer to its rooting system away from common purslane roots. This weed is known to respond to P fertility (see Chapter 3). Competition for P may be one of the primary mechanisms of interference in lettuce-common purslane complexes. However, competition for nutrients can interact with or enhance competition
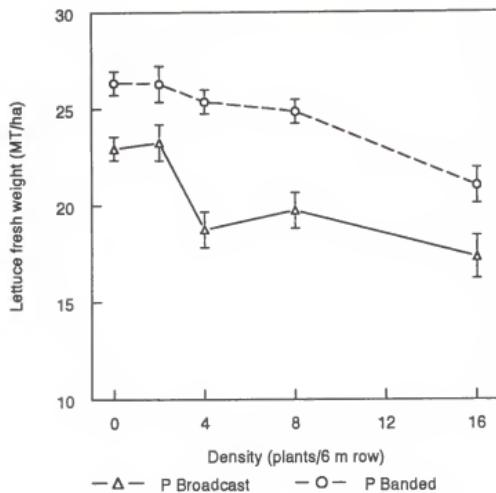
Figure 5-1. Effects of smooth pigweed densities on lettuce head fresh weight.
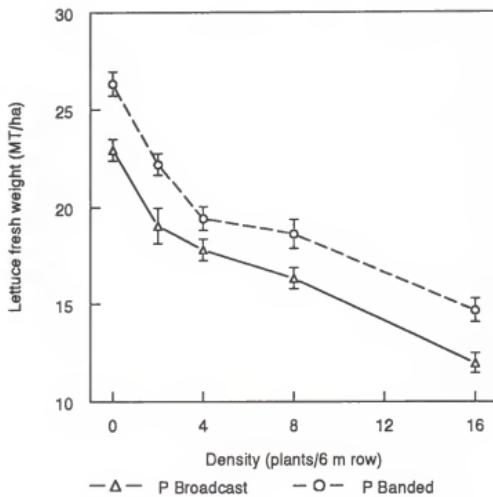
Figure 5-2. Effects of common purslane densities on lettuce head fresh weight.
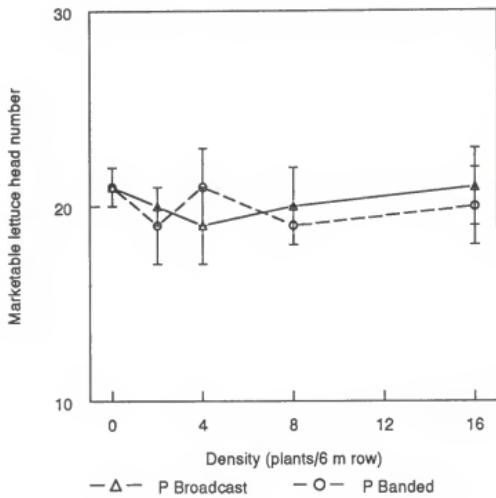
Figure 5-3. Effects of smooth pigweed densities on lettuce head number.
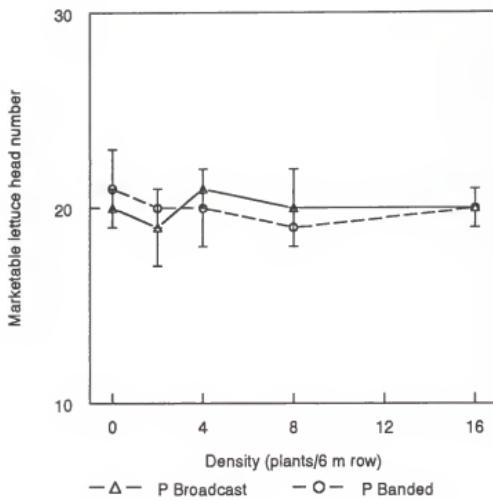
Figure 5-4. Effects of common purslane densities on lettuce head number.
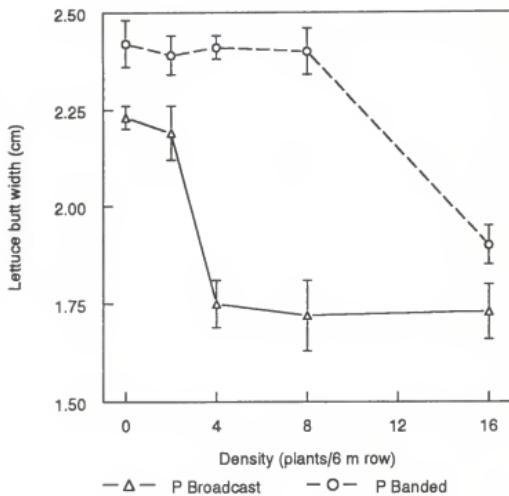
Figure 5-5. Effects of smooth pigweed densities on lettuce butt width.
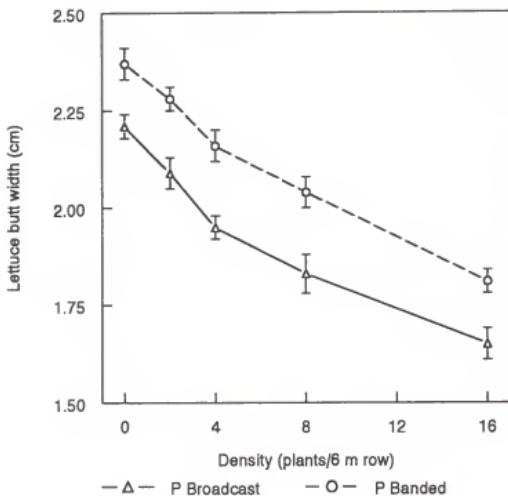
Figure 5-6. Effects of common purslane densities on lettuce butt width.
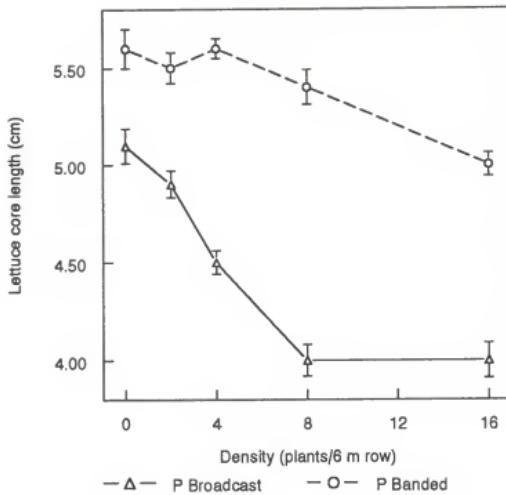
Figure 5-7. Effects of smooth pigweed densities on lettuce core length.
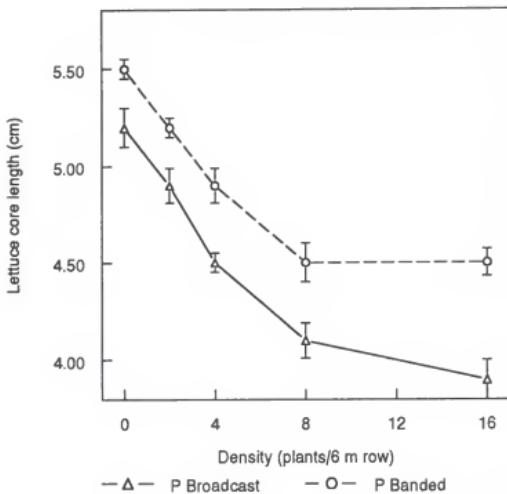
Figure 5-8. Effects of common purslane densities on lettuce core length.
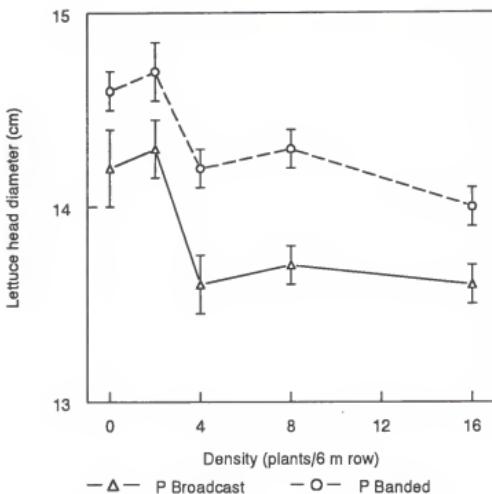
Figure 5-9. Effects of smooth pigweed densities on lettuce head diameter.
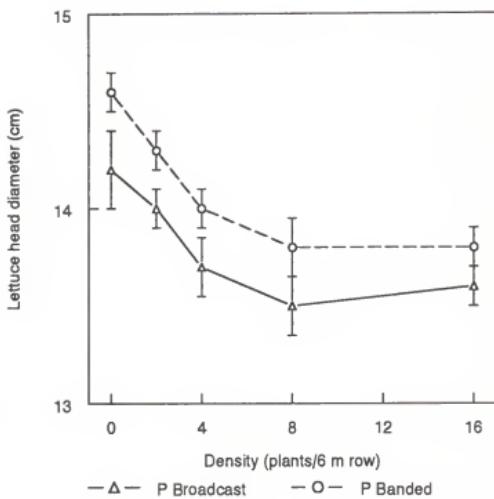
Figure 5-10. Effects of common purslane densities on lettuce head diameter.

for other essential factors, such as light and water (DiTomaso 1995). This may be possible in broadcast P situations, where common purslane grows more quickly and subsequently may shade lettuce more effectively due to enhanced P uptake.

These nutrient-light interactions are not rare in weed-crop interactions, where weeds are favored by high soil fertility more than the crop, growing taller and reducing the amount of solar radiation received by the crop canopy (Liebman and Robichaux 1990; Okafor and DeDatta 1976). Further research is needed to determine the extent of interference of these weeds on the growth of lettuce when different initial removal times are imposed, as well as studies about the specific mechanisms of smooth pigweed and common purslane interference with the crop.

Conclusions

The results obtained led to the rejection of the null hypotheses and the acceptance of the alternative hypotheses that a) P placement had an influence on the yield of lettuce as affected by smooth pigweed densities under field conditions, and b) P placement had an influence on the yield of lettuce as affected by common purslane densities under field conditions. Banding P in lettuce fields was shown to have different effects on the extent and the nature of weed interference of these two weeds. In this case, smooth pigweed and common purslane reacted differently in terms of their effect on lettuce growth and yield.

Along with the results shown in Chapter 4, the data collected suggests two possible explanations about smooth pigweed-lettuce and common purslane-lettuce interactions. First, smooth pigweed, which was not responsive to P fertilization, however,

took up P luxuriously, and was more competitive than lettuce, may absorb P at the expense of the crop. When P is concentrated closer to the lettuce rooting system as in the banded treatment, a positive impact on crop growth was observed in two directions: a) enhanced competitiveness, and b) increased opportunity to absorb P before smooth pigweed roots were present in the lettuce rhizosphere. Changes in lettuce competitiveness are reflected in the change of the critical density necessary for smooth pigweed to reduce yields under the two fertility regimes. Second, common purslane, which was dependent upon P for growth and development, had no change in the critical density necessary to reduce lettuce yields under the two fertility regimes. This finding indicated that banding P benefited lettuce primarily by moving P away from common purslane roots, giving the crop time to develop its root system and acquire P before the more aggressive common purslane roots.

Further research will concentrate on determining the effects of varying initial smooth pigweed and common purslane removal times on lettuce growth as affected by P placement, as well as characterizing the mechanisms of interference of both weeds with lettuce.

CHAPTER 6
EFFECTS OF SMOOTH PIGWEED AND COMMON PURSLANE
INITIAL REMOVAL TIMES ON LETTUCE YIELDS UNDER DIFFERENT
PHOSPHORUS FERTILITY REGIMES

Introduction

Weed interference with vegetable crops is one of the main components of yield

reductions in agricultural settings. In most cases, high economic inputs are needed for

management. Weed competition occurs mainly for nutrients, water, light and space. These

factors, when provided to crops in necessary amounts, cause maximum stimulus of the

crop genetic potential. Competition is related to the ability of individual species to exploit

essential factors efficiently (Tilman 1982). Among these essential factors, nutrients have

been recognized as an important source for crop-weed interactions (DiTomaso 1995).

Although, nutrients are known to influence competitive interactions, little attention has

been offered in the past to these types of studies.

Phosphorus, one of the most important macroelements for plants, is a relatively

immobile nutrient in the soil profile (Sample et al. 1980). Histosols are not an exception,

requiring P fertility because soil levels are unavailable to crops (Hochmuth et al. 1994;

Sanchez 1990). Crisphead lettuce (*Lactuca sativa* L.) production in Florida is mostly

concentrated in the Everglades Agricultural Area (EAA). Because most lettuce is grown

in muck soils, high P rates need to be provided to the soil to satisfy the crop's

requirements. However, weeds are often more aggressive than crops absorbing nutrients, particularly P, which requires a profuse root system to enhance uptake. Therefore, P placement in the soil plays a significant role in the extent and nature of competitive interactions between weeds and crops. Shrefler et al. (1994b) showed that duration of spiny amaranth (*Amaranthus spinosus* L.) interference and method of P application interactively influenced lettuce biomass accumulation in high-organic matter soils.

Some of the most important weeds in the EAA are common purslane and smooth pigweed. When grown unchecked, these species could cause significant lettuce yield reductions. However, reports about the extent of interference of these weeds with lettuce under different P regimes and rates have not been offered. At the same time, public pressure to reduce P utilization in agricultural fields where potential water table pollution may occur (Windemuller et al. 1997), have prompted researchers to devise new weed management strategies. This is particularly true for lettuce production, where weed control methods used are hoeing and cultivation, which can be expensive and cause damage to the root system.

The extent of the damage caused by a given weed on a crop is a function of the duration of interference that the weed is allowed to interfere with the crop. Previous research has shown that fertilizer placement and rates have an impact on the duration of interference of certain weeds with crops. Rasmussen (1995) determined that the negative effect of downy brome (*Bromus tectorum*) can be reduced during the first six weeks by banding N or P in wheat fields. Leafy vegetables are known to be weak competitors with weeds. The short stature and slow-growing nature of these crops enable erect weeds to

interfere effectively during the first few weeks of growth. Previous studies have suggested that lettuce yield reductions due to spiny amaranth competition occurs during the first five weeks (Dusky et al. 1988). A detailed explanation about the duration of smooth pigweed and common purslane interference necessary to reduce lettuce yields is needed by farmers who might be able to utilize better management alternatives for these weeds and reduce the economic inputs.

There are no reports about the influence of smooth pigweed and common purslane duration of interference on lettuce yields as affected by P application method and rate.

The null hypotheses to test in this study were:

a) There are no effects of different P fertility regimes and initial smooth pigweed removal times on lettuce yields, and

b) There are no effects of different P fertility regimes and initial common purslane removal times on lettuce yields.

The specific objective to accomplish was to determine the influence of smooth pigweed and common purslane duration of interference on lettuce as affected by P application method.

Materials and Methods

The influence of initial removal times of smooth pigweed and common purslane on lettuce marketable fresh weight was assessed under field conditions at the Everglades Research and Education Center of the University of Florida in Belle Glade. Two trials were conducted from October 1996 to January 1997, and from September to December

1997. Soil was classified as a Pahokee muck (Euic hyperthermic Lithic Medisaprist), low in P content as revealed by soil tests (3.0 mg P L^{-1}), which is unsatisfactory for lettuce production (Hochmuth et al. 1994; Sanchez et al. 1990). Average temperature during the day and night was 28 and 17°C, respectively. Percent organic matter was about 75% with a soil pH of 6.3. Following soil test recommendations, 250 or 125 kg·ha^{-1} P was either broadcast or banded 2 to 5 cm beneath each lettuce row, depending on the treatments to be established. Other plant nutrients were broadcast to the study area following soil analysis and recommendations for the area.

Two rows of crisphead 'South Bay' lettuce were directly seeded on 0.9 m-wide planting beds, with 30 cm between lettuce rows. One week after crop emergence, lettuce was thinned to a distance of approximately 30 cm in row. Ten days before lettuce planting, smooth pigweed and common purslane seeds were sown in styrofoam multi-cell trays (24 cm^3 $cell^{-1}$) and grown until they reached the two-true leaf stage. Seedlings in the two-true leaf stage (approximately 5 cm in height) of either smooth pigweed or common purslane were transplanted between the two lettuce rows at a density of 16 plants per 6 m row (5.4 m^2), equivalent to 3.00 plants m^{-2}. Duration of interference was achieved by removing the weeds 2, 4, 6 or 8 weeks after lettuce emergence. A weed-free control was established. Unwanted weeds were removed by hand and/or hoeing.

A split-plot design was utilized, with P regimes being the main plots and weed removal time as subplots. A factorial arrangement was established with two P fertility regimes, two weed species, five weed removal times and four replications. The central 50% of the surface area of each experimental unit was harvested when lettuce plants in

weed-free controls reached maturity based on head firmness, size, and appearance. Outermost wrapper leaves were removed and discarded before weighing heads. Marketable lettuce head number, head fresh weight, butt width, core length and head diameter were measured at harvest. Butt width, core length and head diameter were measured to determine lettuce head quality. Current market standards show that loose heads with excessively long (>7.5 cm) stem core and wide butts are not desirable for marketing purposes (USDA 1985).

Data was subjected to analysis of variance (ANOVA) at the 5% significance level (P=0.05) to test for single factor effects and interactions (SAS Inst. 1987). Since no significant treatment by trial interactions were found, data from the two trials were combined for analysis purposes. Treatment means were compared using standard errors calculated from the resulting data for each measured variable.

Results and Discussion

Smooth Pigweed-Lettuce Studies

Phosphorus fertility regime and removal time interactively (P<0.05) affected lettuce fresh weight, butt width, core length and head diameter, but not marketable head number (Figures 6-1, 6-3, 6-5, 6-7 and 6-9). For both P application methods, lettuce fresh weight decreased as length of interference increased. When P was banded, differences in lettuce fresh weight were observed after 4 weeks of interference (approximately 16% yield losses compared with the weed-free control), whereas yield reductions of about 20% were observed after 2 weeks when P was broadcast. Increased lettuce yield was observed when

P was banded compared with broadcast application. Maximum yield reductions of approximately 25 and 30% occurred after 8 weeks of interference for banded and broadcast P, respectively, compared with their weed-free controls. In broadcast treatments, there were no differences in lettuce yield after 4, 6 or 8 weeks of competition. Because lettuce head number was not affected by removal time of this weed, the effect of duration of smooth pigweed interference on the crop is most likely due to the reduction of weight of individual lettuce heads.

Butt width, core length and head diameter are lettuce quality indicators (USDA 1985). Usually, excessively long cores and wide butts are undesirable for market purposes. However, core length, butt width and head diameter are related to the head fresh weight obtained. Small lettuce heads will have very short cores, narrow butts and reduced head diameters caused by diminished fresh weight. Under the conditions of these experiments, broadcast P resulted in reduced butt width, core length and head diameter within each removal time compared to banded P treatments (Figures 6-5, 6-7 and 6-9). Under weed-free conditions, 7, 6 and 4% increases in butt width, core length and head diameter were measured when P was applied banded compared to broadcast. After 4 weeks of smooth pigweed interference, no differences with respect to the control were observed in these variables when P was banded, whereas reductions of 15, 19 and 5% occurred during the same length of time when P was broadcast.

These findings suggest that banding P may reduce the negative impact of smooth pigweed inteference in lettuce production by lengthening the time frame before control measures must be undertaken (about 2 weeks), allowing farmers more flexibility in

scheduling weed management. It appears that banding P gives lettuce an additional advantage to absorb necessary P amounts before smooth pigweed interference becomes critical.

Common Purslane-Lettuce Studies

Significant P fertility regime by common purslane removal time interactions ($P<0.05$) were observed for lettuce fresh weight, butt width, core length and head diameter (Figures 6-2, 6-6, 6-8 and 6-10). Number of marketable lettuce heads per treatment was not affected by either P fertility regimes or removal times (Figure 6-4). In weed-free situations, lettuce head fresh weight was enhanced by banding P compared with broadcast applications, representing a net increase of about 16% in yield (Figure 6-2). When P was banded, common purslane interference caused significant lettuce yield reduction (38%) after 8 weeks of interference compared with the weed-free control. On the other hand, this period of time was 4 to 6 weeks when P was broadcast (24% loss in yield on average). Since the number of lettuce heads remained the same in all treatments, the effect of this weed on lettuce yield appeared to be a reduction of individual head weights.

As described previously, butt width, core length and head diameter are quality indicators for lettuce heads (USDA 1985). Under normal conditions, core length, butt width and head diameter are functions of head fresh weight. Small lettuce heads will have very short cores, narrow butts and reduced head diameters caused by diminished fresh weight. Values of butt width, core length and head diameter followed patterns similar to that for head fresh weight (Figures 6-6, 6-8 and 6-10), where banded treatments
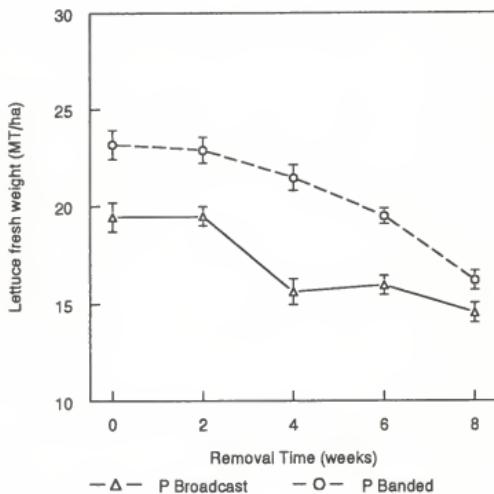
Figure 6-1. Effects of smooth pigweed removal times on lettuce head fresh weight.
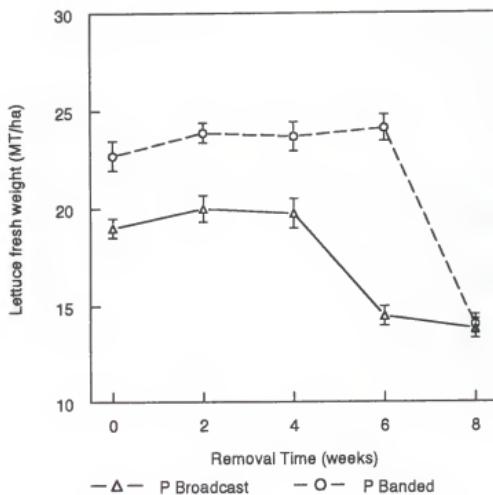
Figure 6-2. Effects of common purslane removal times on lettuce head fresh weight.
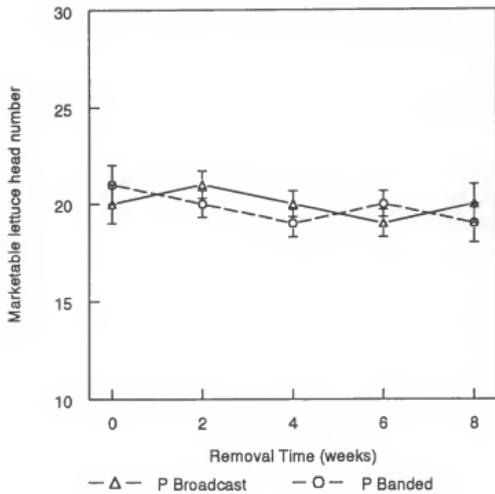
Figure 6-3. Effects of smooth pigweed removal times on lettuce head number.
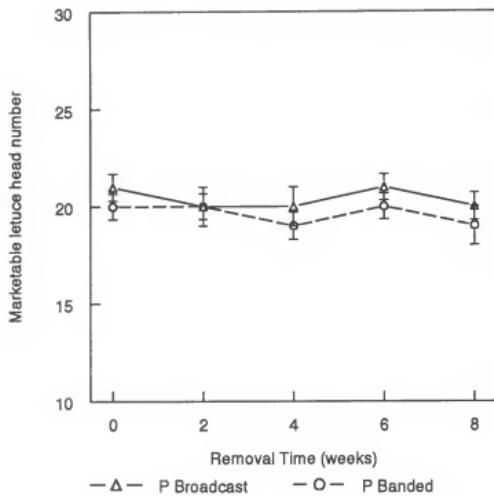
Figure 6-4. Effects of common purslane removal times on lettuce head number.
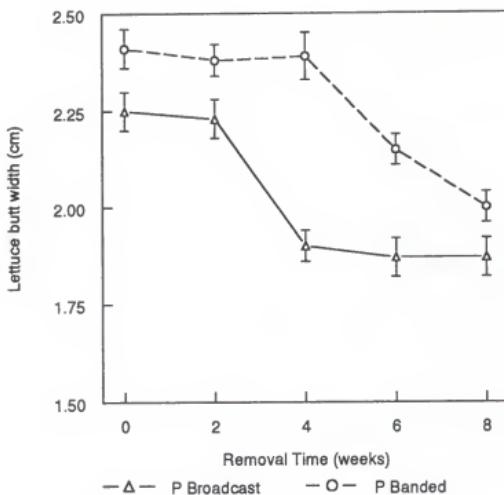
Figure 6-5. Effects of smooth pigweed removal times on lettuce butt width.
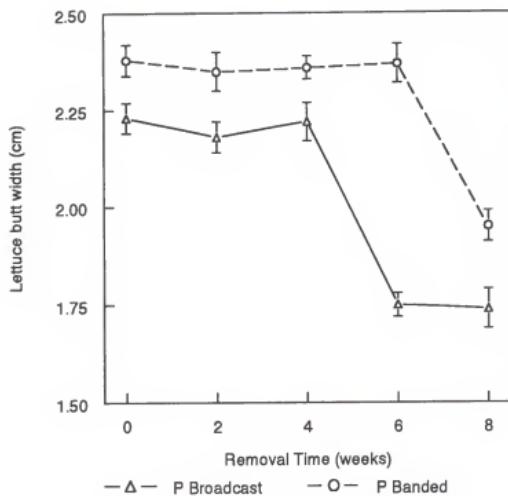
Figure 6-6. Effects of common purslane removal times on lettuce butt width.
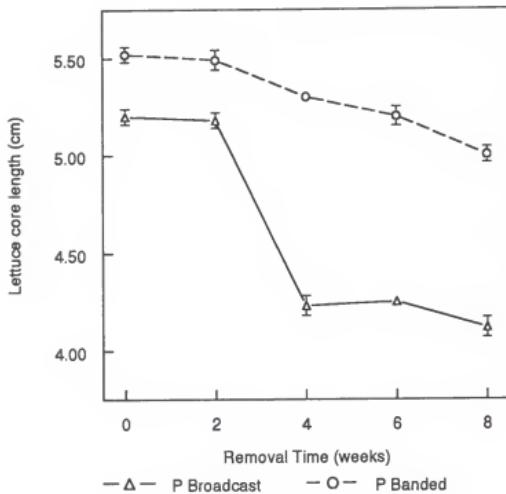
Figure 6-7. Effects of smooth pigweed removal times on lettuce core length.
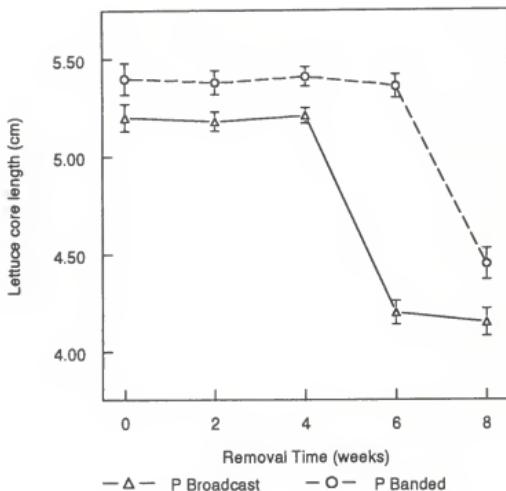
Figure 6-8. Effects of common purslane removal times on lettuce core length.
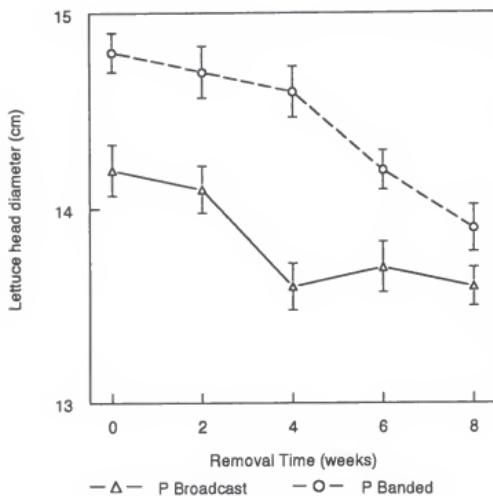
Figure 6-9. Effects of smooth pigweed removal times on lettuce head diameter.
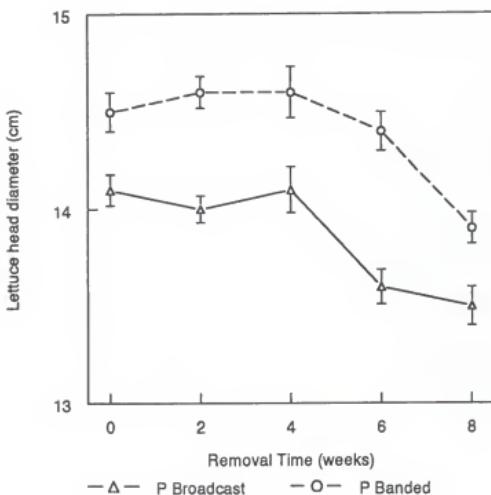
Figure 6-10. Effects of common purslane removal times on lettuce head diameter.

showed larger values than broadcast P treatments. In banded situations, there were no differences in these variables through 6 weeks. Thereafter, 18, 18 and 5% decreases in butt width, core length and head diameter, respectively, were measured compared to the no-interference banded control. When P was broadcast, no differences were observed through 4 weeks, declining 22, 20 and 5% for each respective variable.

The data analyzed indicated that the duration of common purslane-lettuce competition could be altered by modifying P fertilization practices. Under the conditions of these studies, the critical duration of interference was increased from changed from 4 to 6 to 6 to 8 weeks with respect to common purslane interference by changing from broadcasting to banding P.

Conclusions

The results obtained led to the rejection of the null hypotheses and the acceptance of the alternative hypotheses that: a) there were significant effects of different P fertility regimes and initial smooth pigweed removal times on lettuce yield, and b) there were significant effects of different P fertility regimes and initial common purslane removal times on lettuce yield. Based on previous results discussed in Chapters 4 and 5, the data collected in these studies supports the theory that banding P changes the nature of the competitive interactions of smooth pigweed-lettuce and common purslane-lettuce associations. There are two possible explanations for the increased time frame necessary to reduce lettuce yields: a) banding concentrated P closer to the lettuce rooting system, causing an increase in lettuce competitiveness, therefore reducing the negative impact of

the weeds, and b) banding allowed lettuce to capture larger P amounts in early stages before weed roots had the opportunity to absorb the nutrient. These results agree with those described by Rasmussen (1985) and Shrefler et al. (1994b) where banding fertilizer lengthened the time frame necessary for weeds to reduce yield in comparison with broadcast applications. Further studies will focus in determining the specific mechanisms of interference of these weeds on lettuce as affected by P rates.

CHAPTER 7
ABOVE AND BELOW GROUND INTERFERENCE OF SMOOTH PIGWEED AND COMMON PURSLANE ON LETTUCE AS AFFECTED BY PHOSPHORUS FERTILITY

Introduction

In previous experiments, a detailed description of the phenomena of smooth pigweed and common purslane interference with lettuce as affected by varying phosphorus (P) rates and application placement has been offered. However, no mechanism of interference for each weed species has been determined in terms of their effects on plant growth and nutrient uptake. In the following chapters, the responses of both weeds and lettuce to changing resource conditions are described.

Mechanisms of interference are related to both the effect that plants have on resources as well as the response of plants to changed resources (Goldberg 1990). These resources (light, nutrients, water and space), when supplied in limited amounts, can change the competitive interactions between two plant species (Tilman 1982). Light plays an important role in the overall interference relationships among species (Radosevich et al. 1997). As it is well known, this factor is the energy source used to convert inorganic compounds to organic molecules during the process of photosynthesis (Salisbury and Ross 1984). Therefore, when radiance levels and quality are reduced, significant changes in plant responses can be observed. These responses vary from mortality to plasticity

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expressed as redistribution of dry matter, altered leaf anatomy and decreased respiration rates (Patterson 1985). It is generally understood that an aggressive competitor species is very plastic to shading, usually adapting to low light levels or change in growth habits.

Plant nutrients are usually in limited concentrations in the soil solution, justifying the use of supplementary fertilizers to replenish supply (DiTomaso 1995). Unfortunately, nutrients applied to the soils are also available for weeds, establishing competitive relationships. In most farming systems, competition for nitrogen is the most important source of nutrient interference (DiTomaso 1995). However, in organic soils, this element is frequently found in sufficient amounts for crop production, minimizing the effects of weed interference for this nutrient. On the other hand, because Histosols are naturally deficient in P, weed-crop competition for this nutrient occurs.

Competition for a given factor is not independent of competition for other resources (DiTomaso 1995). The influence of a given limited resource (i.e. nutrients) can change the balance and nature of the interference for another resource (i.e. light) (Carlson and Hill 1986; Liebman and Robicheaux 1990). In other words, the enhanced ability of a given species to deplete nutrients from the soil faster than another may provide it an additional advantage to shade its competitor. The opposite situation may also occur, with tall plants being able to capture sunlight more efficiently, leading to more vigorous below ground growth and subsequently being able to exploit soil nutrients more efficiently.

In order to avoid confounding results in terms of the main factor involved in weed-crop complexes, a partitioning approach of above and below ground competition has been devised. Under this methodology, the crop and the weed are grown under each of four conditions: a) no interference, b) full interference, c) above-ground interference, and d) below-ground interference (Groves and Williams 1975; Silvertown 1987). This partitioning allows separation and comparison of the effects of unrestricted individual growth (no interference) with below ground competition (water and/or nutrients) and above ground competition (light).

The null hypotheses to test in this study were:

a) There are no above and below ground interactions between smooth pigweed and lettuce as affected by varying P rates, and

b) There are no above and below ground interactions between common purslane and lettuce as affected by varying P rates.

The overall objectives were a) to determine the effect of different partitioning conditions on smooth pigweed and lettuce biomass accumulation, b) to determine the effect of different partitioning conditions on common purslane and lettuce biomass accumulation, c) to determine the primary mechanism of interference of smooth pigweed with lettuce as affected by P fertility rate, and d) to determine the primary mechanism of interference of common purslane with lettuce as affected by P fertility rate.

Materials and Methods

Partitioning studies were conducted under greenhouse conditions during fall 1996 and spring 1997 at the University of Florida, Gainesville. Lettuce-smooth pigweed and lettuce-common purslane trials were conducted separately during each season. Average day/night temperatures were 28/24 and 25/21°C during fall and spring trials, respectively. Lettuce (cv. South Bay), smooth pigweed and common purslane seeds were sown in styrofoam multi-cell flats (5 cm^3 cell^{-1}). When seedlings reached the two-true leaf stage, lettuce-smooth pigweed and lettuce-common purslane complexes were transplanted according to four partitioning regimes: no interference (NI), full interference (FI), below-ground interference (BI), above-ground interference (AI).

For NI treatments, two plastic containers holding 3 L of screened Pahokee muck (Euic hyperthermic Lithic Medisaprist) were utilized, planting a single lettuce seedling in the center of one of the containers and a single weed seedling in the center of the other container. Seedlings of both the crop and the weed involved were in the two-true leaf stage. Hardware cloth was utilized to restrict aerial space above each container to approximate the same volume as the below-ground volume. Therefore, plants growing in NI treatments would have approximately 3 L each of soil and aerial volume to grow.

For FI treatments, one seedling of each, lettuce and the weed, involved were planted simultaneously into the same container equidistant from the center of the container. A volume of 6 L of the same soil described previously was used. Similar aerial volume for each species was restricted by using hardware cloth. Two different modifications to this approach were implemented for AI and BI treatments. For AI

treatments, each 6 L container was divided into two equal soil chambers by using flat pieces of plastic material that allowed isolation of water, nutrients and root growth within each soil chamber. Aerial volume remained as for FI treatments. Therefore, for AI treatments, each species involved had 3 L of soil while sharing 6 L of aerial space. For BI treatments, each species shared 6 L of soil volume, while hardware cloth was utilized to create two above-ground chambers of 3 L each. This procedure was utilized to avoid canopy overlapping.

Soil utilized was low in P for optimum lettuce yields as revealed by soil tests (water extractable P of 3.0 mg P L^{-1} of soil). Phosphorus was added at rates of 0, 0.4 and 0.8 g of P L^{-1} of soil, using $Ca(H_2PO_4)_2$ as the P source, and thoroughly mixed with the soil 5 days prior to transplant. Other plant nutrients were provided every 5 days with a non-P modified nutrient solution composed of 571 ppm NH_4NO_3, 777 ppm KNO_3, 555 ppm $CaCl_2$, 250 ppm $MgSO_4$, 24 ppm $FeSO_4 \cdot 7H_2O$, 1.80 ppm $MnCl_2 \cdot 4H_2O$, 2.82 ppm H_3BO_3, 0.22 ppm $ZnSO_4 \cdot 7H_2O$, 0.08 ppm $CuSO_4 \cdot 5H_2O$, and 0.02 ppm MoO_3, dissolved in 1 L of deionized water. Containers were watered daily during the first 5 days after transplanting with 0.5 L of deionized water per L of soil. Afterwards, 1 L of deionized water per L of soil was provided every 2 days. These procedures were implemented to alleviate competition for water and nutrients other than P in crop-weed associations.

Treatments were factorially arranged within a split-plot design with 3 P rates as main plots and 4 partitioning regimes as sub-plots. Four replications were established. Weed and lettuce plant height, and shoot and root dry weights were collected 25 days after transplanting. Shoot and root samples were individually washed by immersing

individuals in water with a 0.1% Liqui-nox detergent solution (phosphate free detergent) for about 10 seconds, and then washed for one minute with a 3% (v/v) solution of HCl. Finally, samples were rinsed with deionized water and placed in paper bags. Plant material was dried at 70°C for 10 days in a forced air oven, weighed and ground in a Wiley mill using a stainless steel screen with 1 mm diameter holes. Ground samples were stored in air-tight plastic bags for further nutrient analysis. Representative subsamples were obtained after thoroughly mixing ground samples for each treatment. Wet-ash digestion was used to obtain liquid extract from tissues (Wolf 1982). Phosphorus content was determined colorimetrically using the molybdate-ascorbic acid solution method (Murphy and Riley 1962).

Resulting data obtained was subjected to analysis of variance (ANOVA) to test for treatment effects. If significant differences were found, treatment means were separated with standard error. The data from the two trials were pooled, since no significant (P<0.05) trial by treatment interactions were found.

Results and Discussion

Smooth Pigweed-Lettuce Studies

Partitioning regimes and P rates interactively (P<0.05) influenced lettuce shoot and root dry weight, and height (Figure 7-1, 7-3, and 7-5). However, smooth pigweed biomass variables and plant height were not affected by either P rate or partitioning regimes (Figures 7-2, 7-4 and 7-6). Maximum values for lettuce shoot and root dry weight, and height were observed for NI treatments within each P rate (Figures 7-1, 7-3 and 7-5).

Lowest biomass production and height were measured in FI treatments. Lettuce shoot and root dry weight, and height increased with P rate within each partitioning regime.

Lettuce shoot dry weight was reduced 27, 27 and 26% compared with the NI control when smooth pigweed root interference was allowed (BI) at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively (Figure 7-1). When grown under AI regimes, lettuce shoot dry weight was reduced by 49, 49 and 51% at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. As both species were allowed to interfere freely with each other (FI), lettuce shoot dry weight declined even further within each P rate. Reductions of 73, 65 and 64% occurred at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively, which were higher than the two previously described interference regimes.

Reductions in lettuce root dry weight due to smooth pigweed root interference (BI) were 40, 31 and 32% when P was supplied at rates of 0, 0.4 and 8 g P L^{-1} soil, respectively (Figure 7-3). When smooth pigweed shoots were allowed to interfere (AI), lettuce root dry weight declined 65, 58 and 58% compared with NI treatments at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. When both shoot and root interference occurred (FI), reductions in lettuce root dry weight accounted for 85, 82 and 79% with respect to NI treatments for 0, 0.4 and 8 g P L^{-1} soil, respectively.

Smooth pigweed root interference (BI) negatively influenced lettuce plant height by 27, 29 and 28% at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively (Figure 7-5). If AI occurred, then lettuce height reductions reached 45, 43 and 39% compared with NI control for 0, 0.4 and 8 g P L^{-1} soil, respectively. Lettuce height declined 64, 57 and 55%

as smooth pigweed shoot and roots interfered (FI) with the crop at P rates of 0, 0.4 and 8 g L^{-1} soil, respectively.

Lettuce tissue P content was interactively affected by P rate and partitioning regime, whereas only P rate influenced tissue P content of smooth pigweed (Figures 7-7 and 7-8). Lettuce tissue P content followed the same pattern as shoot and root dry weight per plant, increasing with P rate applied. In the absence of weed interference (NI), lettuce tissue P content had the highest values within each P rate compared with the other regimes. When smooth pigweed was allowed to interfere both above and below ground (FI), tissue P content reductions of 84, 77 and 74% occurred at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. If shoot interference was allowed, then lettuce tissue P content declined 59, 58 and 58% compared with NI treatments at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. Smooth pigweed root interference (BI) accounted for 35, 33 and 32% reductions in tissue P content of the crop at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively.

Tissue P content of the weed increased with increasing P rate (Figure 7-8). Partitioning regime did not have an effect on smooth pigweed tissue P accumulation. Because shoot and root dry weight of the weed did not change with varying P rate and partitioning regimes, these findings indicated that smooth pigweed had increased P absorption from the soil without producing any change in the weed biomass, indicative of luxurious P consumption by smooth pigweed.

Smooth pigweed shoot interference (AI) accounted for most of the negative impact caused by the weed compared with the combined effects of shoot and root
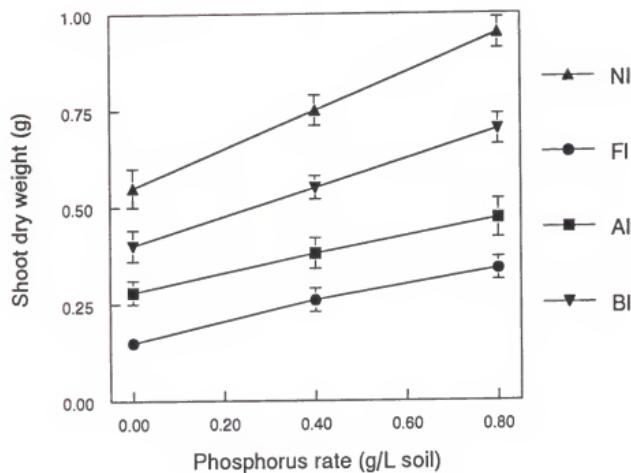
Figure 7-1. Effect of phosphorus (P) rates on lettuce shoot dry weight per plant.
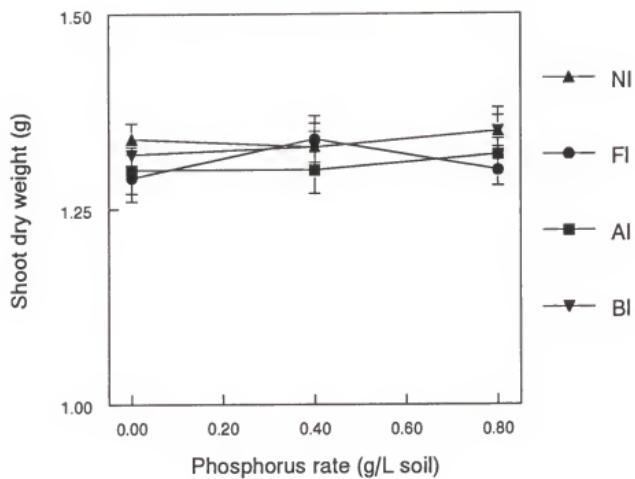
Figure 7-2. Effect of phosphorus (P) rates on smooth pigweed shoot dry weight per plant.
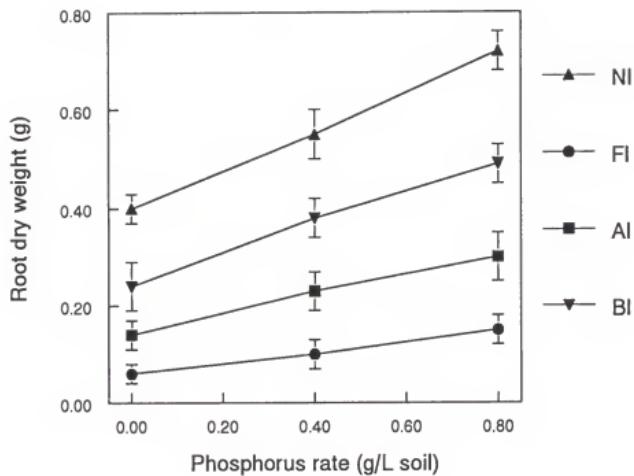
Figure 7-3. Effect of phosphorus (P) rates on lettuce root dry weight per plant.
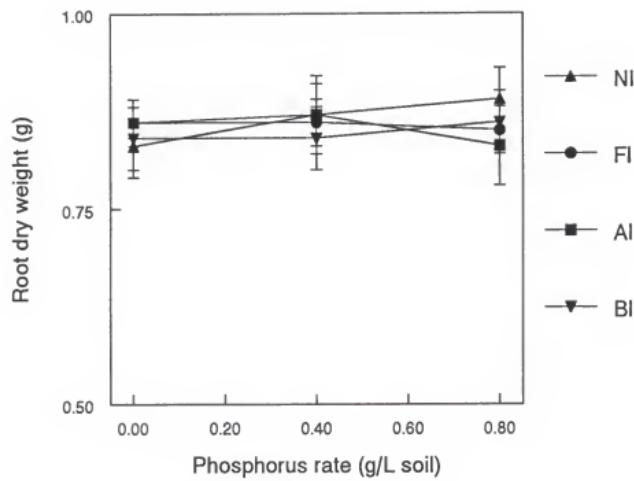
Figure 7-4. Effect of phosphorus (P) rates on smooth pigweed root dry weight per plant.
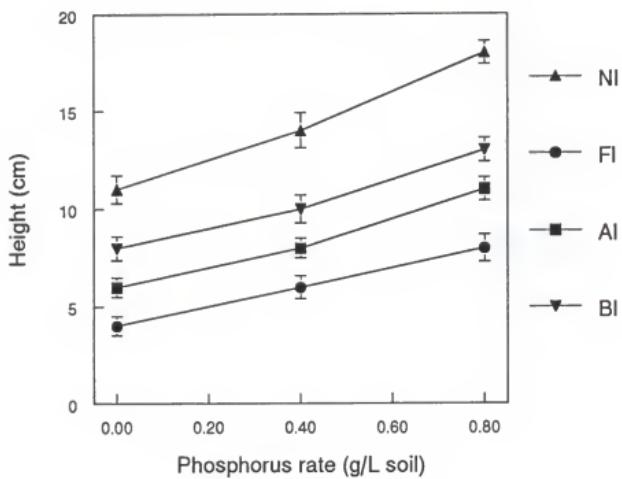
Figure 7-5. Effect of phosphorus (P) rates on lettuce plant height.
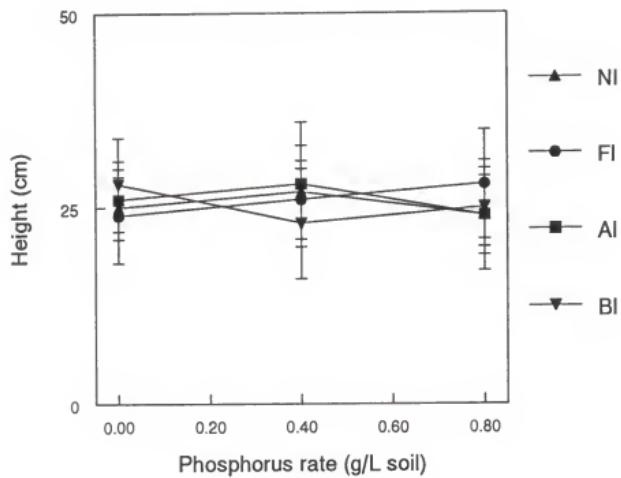
Figure 7-6. Effect of phosphorus (P) rates on smooth pigweed plant height.
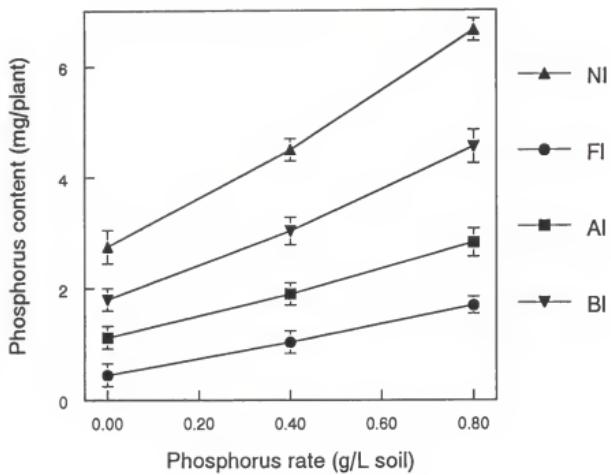
Figure 7-7. Effect of phosphorus (P) rates on lettuce P content per plant.
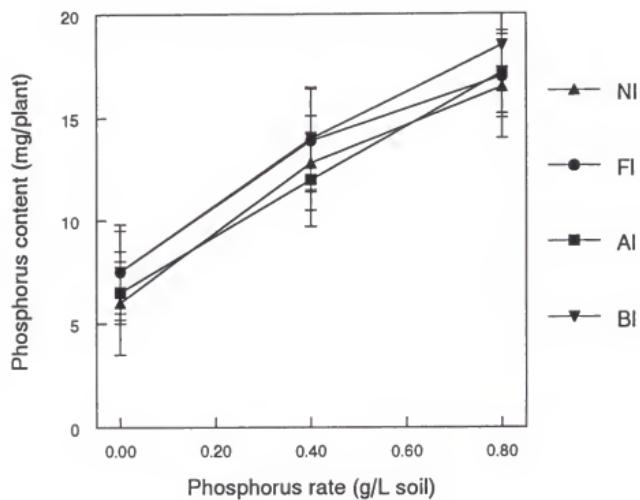
Figure 7-8. Effect of phosphorus (P) rates on smooth pigweed P content per plant.

interference (FI). Light interception by taller smooth pigweed plants deprived lettuce foliage the opportunity of capturing light necessary for growth. Under the conditions of these studies, the primary mechanism of smooth pigweed interference with lettuce appears to be light interception by the weed canopy. A secondary mechanism of interference was the luxurious P absorption by the weed root system. It appears that this luxurious P consumption is at the expense of lettuce. The allelopathic effects, if any, by smooth pigweed roots cannot be ruled out as a possible contributor to the smooth pigweed impact on lettuce. However, allelopathic compounds are usually released when plants are growing under stress conditions (Patterson 1986). In this case, because smooth pigweed shoot and root biomass was not affected by any factor and lettuce response to increased P rates was found, allelopathy is unlikely.

Interactions among interference mechanisms by weeds are not a rare occurrence (Carlson and Hill 1986; Liebman and Robicheaux 1990). In this case, the influence of a given limited resource (light) combined with the changes in availability of another (P) enabled smooth pigweed to reduce lettuce biomass more than if only one mechanism of interference took place.

Common Purslane-Lettuce Studies

Lettuce and common purslane shoot and root dry weight, plant height and tissue P content on a per plant basis were interactively (P<0.05) affected by partitioning regime and P rate. For all lettuce and common purslane variables measured, values increased as P rate applied increased (Figures 7-9, 7-11, 7-13 and 7-15). Highest lettuce shoot and root biomass, height and tissue P content were obtained with no common purslane interference

(NI), decreasing with each partitioning treatment within P rates in the following order: NI>AI>BI>FI. Common purslane variables measured reached maximum values with increasing P rates in the FI treatments.

Lettuce shoot dry weight declined 42, 45 and 44% compared with the NI control at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively, when common purslane shoot interference (AI) occurred (Figure 7-9). As both species were allowed to interfere below ground (BI), further decreases of 67, 63 and 56% were observed at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. Lowest shoot dry weight values were obtained when both shoot and root interference from common purslane (FI) was allowed (decrease of 84, 75 and 71% at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively).

Common purslane shoot interference (AI) caused lettuce root dry weight reductions to reach 53, 47 and 50% for P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively (Figure 7-11). These values increased to 73, 69 and 65% when the weed interfered only below ground (BI), whereas both effects combined resulted in 93, 87 and 85% root dry weight reductions of lettuce compared with NI control.

Reductions in lettuce plant height followed the same pattern observed for shoot and root dry weight (Figure 7-13). Tallest lettuce plants except the NI control were obtained with the AI partitioning, followed by BI treatments, and by FI which accounted for 77, 68 and 67% shoot length inhibition at 0, 0.4 and 0.8 P L^{-1} soil, respectively.

Lettuce tissue P content was also negatively influenced by common purslane interference (Figure 7-15). When only common purslane shoots were allowed to interfere (AI), reductions of 45, 40 and 41% occurred at P rates of 0, 0.4 and 0.8 g P L^{-1} soil,
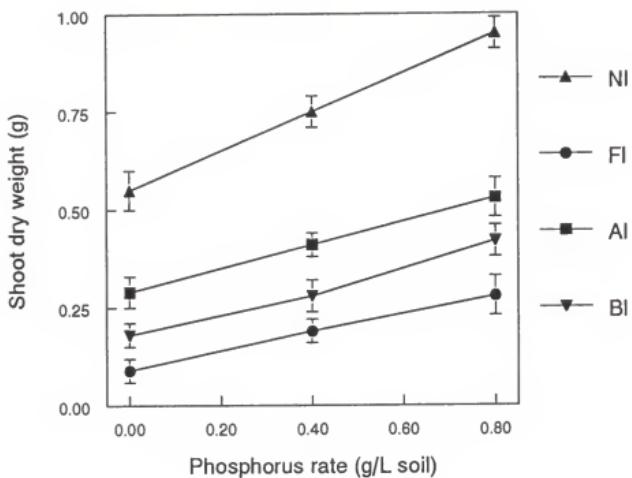
Figure 7-9. Effect of phosphorus (P) rates on lettuce shoot dry weight per plant.
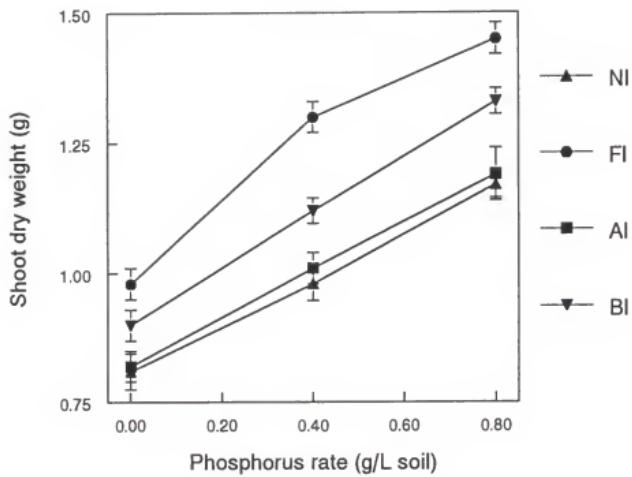
Figure 7-10. Effect of phosphorus (P) rates on common purslane shoot dry weight per plant.
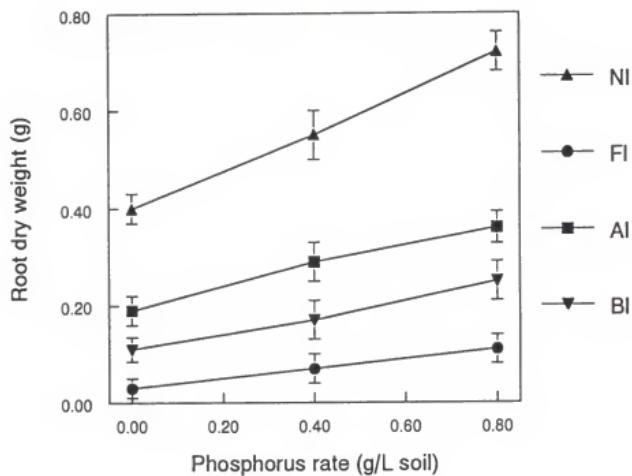
Figure 7-11. Effect of phosphorus (P) rates on lettuce root dry weight per plant.
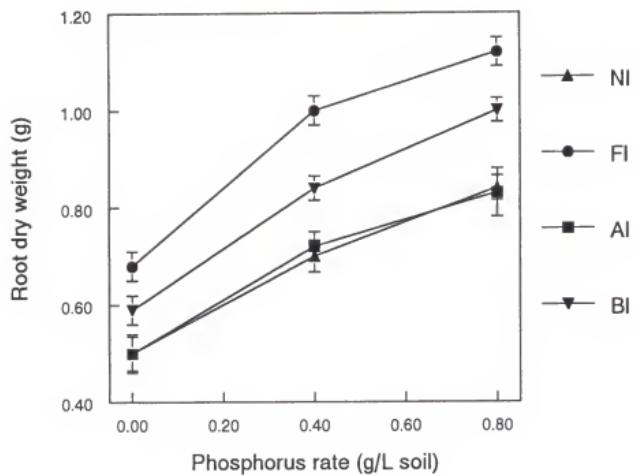
Figure 7-12. Effect of phosphorus (P) rates on common purslane root dry weight per plant.
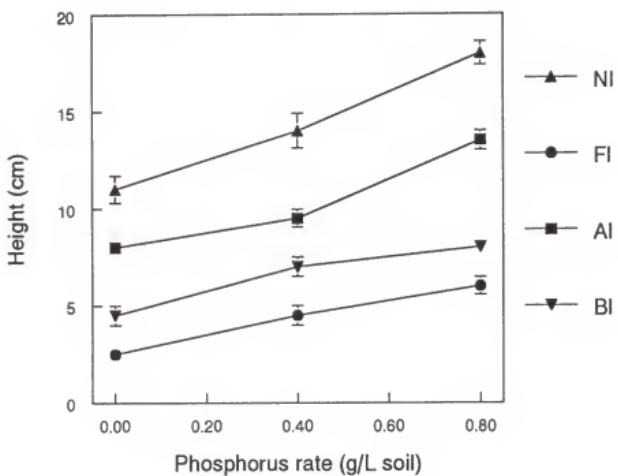
Figure 7-13. Effect of phosphorus (P) rates on lettuce plant height.
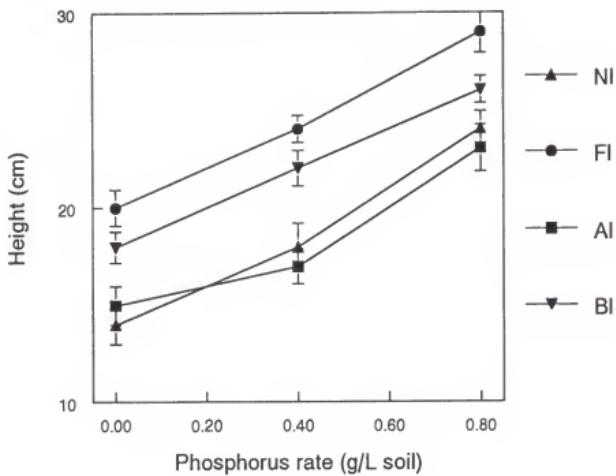
Figure 7-14. Effect of phosphorus (P) rates on common purslane plant height.
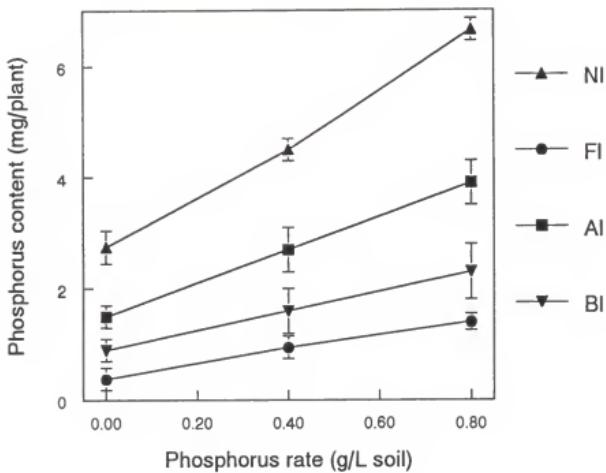
Figure 7-15. Effect of phosphorus (P) rates on lettuce P content per plant.
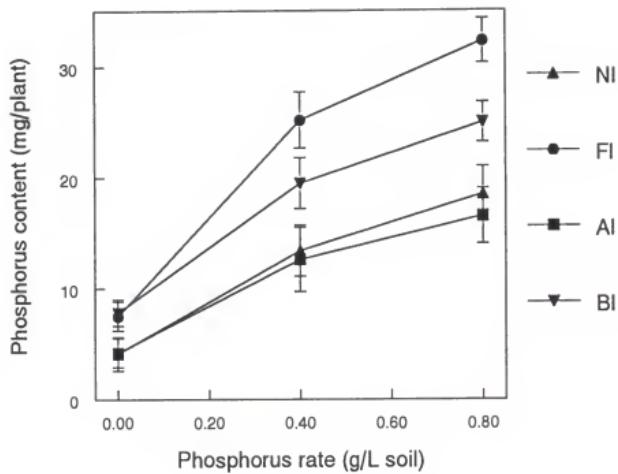
Figure 7-16. Effect of phosphorus (P) rates on common purslane P content per plant.

respectively. As the weed and lettuce roots were allowed to interfere (BI), 67, 64 and 65% reductions were observed at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively. The combined effect of both partitioning treatments (FI) resulted in 86, 79 and 79% decreases at P rates of 0, 0.4 and 0.8 g P L^{-1} soil, respectively, compared with the NI control. No differences were found in common purslane variables measured as affected by either shoot interference (AI) or NI (Figures 7-10, 7-12, 7-14 and 7-16).

The data obtained indicates that common purslane root interference (BI) accounted for the majority of the reduction in lettuce biomass. Since both the weed and lettuce are responsive to P rates, competition for P was the main mechanism of interference of common purslane on lettuce. This conclusion is supported by the fact that common purslane had increased biomass production when shoot and roots were allowed to interfere with lettuce compared with its monoculture. A plausible explanation for this biomass increment is that as the weed was growing in a given soil volume, P became a limiting factor. However, as the container size doubled when FI occurred, P supply also doubled, increasing the possibilities of the weed to capture more of this essential nutrient at the expense of lettuce.

Light interference proved to be a secondary mechanism of interference for the weed. Under the conditions of these studies, it appears that common purslane, which is the most competitive species of the three studied, captures increasing P amounts from the soil, enhancing shoot growth and consequently shading shorter lettuce plants. Okafor and DeDatta (1976) reported similar results when studying interactions between nitrogen (N) rates supplied to rice growing with purple nutsedge (*Cyperus rotundus* L.), where the

mechanism of interference of the weed was a result of an interaction between N uptake and light interception.

Conclusions

The data discussed herein led to the rejection of the null hypotheses and the acceptance of the alternative hypotheses that a) there were above and below ground interactions between smooth pigweed and lettuce as affected by varying P rates, and b) there were above and below ground interactions between common purslane and lettuce as affected by varying P rates.

Smooth pigweed was found to interfere with lettuce primarily through light interception by its taller canopy, depriving the lettuce. A secondary mechanism of interference was the absorption of P from the soil through luxurious consumption, increasing the P tissue content without enhancing smooth pigweed biomass accumulation.

In contrast, common purslane was a very aggressive competitor for P, when competing the lettuce. Because the weed grew taller than lettuce, light interception was a secondary interference mechanism. Further studies should concentrate on characterizing the P uptake rates of both weeds compared with lettuce.

CHAPTER 8
PHOSPHORUS DEPLETION RATES IN HYDROPONICALLY-GROWN LETTUCE-SMOOTH PIGWEED AND LETTUCE-COMMON PURSLANE COMPLEXES

Introduction

In previous chapters, it has been described that varying P rates affect the interference relationships of either smooth pigweed or common purslane and lettuce, as well as the mechanisms of interference of each weed with the crop. However, in order to demonstrate that these weeds are indeed more aggressive than lettuce in capturing P, it is necessary to determine the P depletion rate of each species grow in mixture and in monoculture. This procedure would enable the identification of the relative effects of intra- and interspecific competition for P on each species with regard to biomass accumulation. To determine these interactions, soilless media can to be used to quantify the amount of P absorption by each weed and lettuce. Once P absorption patterns of plant mixtures and monocultures are obtained, then the P absorption rates may be examined to define the relationships between P absorption from a hydroponic solution and time.

The null hypothesis for this study was:

a) There are no effects of each weed species on the P absorbed by lettuce.

The specific objectives to accomplish were a) to determine the influence of varying P concentrations on the growth of lettuce and smooth pigweed in monocultures and

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mixtures in soilless culture, b) to determine the influence of varying P concentrations on the growth of lettuce and common purslane in monocultures and mixtures in soilless culture, and c) to characterize the depletion rate of P from solution by each species over time.

Materials and Methods

Phosphorus Competition Studies

Lettuce-smooth pigweed and lettuce-common purslane complexes were established under greenhouse conditions from March to June 1996 in Gainesville, Florida. Average temperature, daylength and photosynthetic active radiation were 29/24°C, 14 h, and 2050 μmol·m^{-2}·sec^{-1}, respectively. Environmental conditions were monitored daily and averaged over time by using a conventional maximum/minimum thermometer, and a LI-COR LI-185 lightmeter equipped with a standard quantum sensor.

Crisphead lettuce (cv. South Bay), smooth pigweed and common purslane seeds were germinated in multiple cell trays (24 cm^3 cell^{-1}) filled with fine sand 10 days before transplanting. When seedlings reached the two-true leaf stage, they were removed from the trays and their roots were gently rinsed to remove sand. Single plants were placed for 2 hours in acid-washed 0.5 L Erlenmeyer flasks filled with deionized water.

A P-less hydroponic nutrient solution was prepared containing 571 ppm NH_4NO_3, 777 ppm KNO_3, 555 ppm $CaCl_2$, 250 ppm $MgSO_4$, 24 ppm $FeSO_4 \cdot 7H_2O$, 1.80 ppm $MnCl_2 \cdot 4H_2O$, 2.82 ppm H_3BO_3, 0.22 ppm $ZnSO_4 \cdot 7H_2O$, 0.08 ppm $CuSO_4 \cdot 5H_2O$, and 0.02 ppm MoO_3, dissolved in 1 L of deionized water. Preliminary trials showed that this

nutrient solution was effective in enhancing lettuce growth and minimizing stress for essential plant nutrients. Five different P solutions were separately prepared at concentrations of 10, 20, 40, 80 and 160 ppm P, using H_3PO_4 as the P source.

Plastic containers with lids were utilized to establish lettuce-weed combinations. Three different proportions were established for each lettuce-weed complex: a) 2 lettuce plants per container (2:0), b) 2 weeds per container (0:2), and c) 1 lettuce plant and 1 weed per container (1:1). A final solution volume of 200 mL per container was utilized for these experiments. This volume was chosen based on preliminary trials that indicated that it allowed the measurement of lettuce growth changes 20 days after establishment. Plastic containers were covered with aluminum foil to prevent algae growth in the nutrient solution. Three 0.5 cm holes were drilled through each plastic lid, two of which were used to hold the two plants and the third to pump air to the solution for aeration. A volume of 0.5 L air container^{-1} h^{-1} was pumped to the growing solution.

Treatments were established in a split plot design with 5 replications where P concentrations comprised main plots and proportions were subplots. Lettuce-smooth pigweed and lettuce-common purslane complexes were established separately. Plants were allowed to compete for P for 15 days. At harvest time, shoot and root dry weight per plant, shoot and root length per plant, and total tissue P content per plant were determined. Plant samples were wet-ashed at 500°C and soluble extracts were analyzed by the colorimetric procedure of Murphy and Riley (1962). Data from three trials were combined since no significant (P>0.05) trial by treatment interactions were found. Data collected were analyzed for treatment effects with analysis of variance (ANOVA) at the

5% significance level. If significant differences were found (P<0.05), treatment means were separated by standard error.

Phosphorus Depletion Studies

Phosphorus depletion studies were conducted during November and December 1997. Single plants of lettuce, smooth pigweed and common purslane were germinated in multi-cell flats as described previously. Roots of seedlings in the two-true leaf stage were washed in deionized water for 2 hours. A solution containing 20 ppm P in a 7 mL glass tube was prepared to submerse roots of each species at various times. Standard solutions were also prepared at concentrations of 0.1, 10, 20, 40, 80, 125, 250 and 500 ppm P to obtain through regression analysis a calibration curve utilized to detect P concentrations in unknown solutions. A spectrophotometer equipped with a 882 nm filter was utilized to analyze colorimetrically P solutions after various absorption periods by each species (Murphy and Riley 1962; Sanchez 1990).

Root systems of single seedlings per species were submersed in a 20 ppm P solution for 1, 2.5, 5, 10, 20, 40, 60, 90, 180, 360, 720 and 1440 minutes. Ten seedlings of each species were utilized for each time of exposure. After removing plants from P solutions and colorimetrically determining P, data collected was submitted to regression analysis to characterize the relationship between P concentration and time.

Results and Discussion

Phosphorus Competition Studies

Phosphorus concentration and proportion interactively (P<0.05) influenced shoot and root length, shoot and root dry weight, and tissue P content per plant in lettuce-smooth pigweed and lettuce-common purslane complexes. Lettuce monocultures (2:0) showed the highest values for shoot length at a P concentration of 80 ppm or higher, whereas root length was maximized at 40 ppm P with no differences observed thereafter (Figures 8-1 and 8-2). Shoot and root length of smooth pigweed monocultures were not influenced (P>0.05) by varying P concentrations. Common purslane monocultures increased their shoot and root length at P rates of 20 and 40 ppm, declining sharply with higher P concentrations. In lettuce-smooth pigweed mixtures, lettuce shoot and root length increased at P rates of 10 to 20 ppm, with no changes at higher P concentrations, whereas smooth pigweed shoot and root length remained unchanged compared to those grown in monoculture (Figures 8-3 and 8-4). When lettuce was grown in mixture with smooth pigweed, shoot and root length were significantly lower than when grown in monoculture. For lettuce-common purslane complexes, P rate had a profound effect on the response of both species (Figures 8-5 and 8-6). While common purslane increased its shoot and root length at P rates from 10 to 20 ppm, lettuce values declined abruptly within the same range. As P rate increased to 40 ppm, common purslane shoot and root length declined and lettuce increased, with no changes at higher P concentrations.
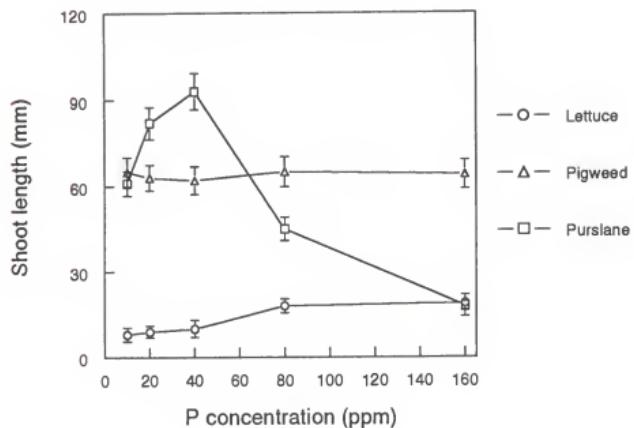
Figure 8-1. Lettuce, smooth pigweed and common purslane shoot length in monoculture.
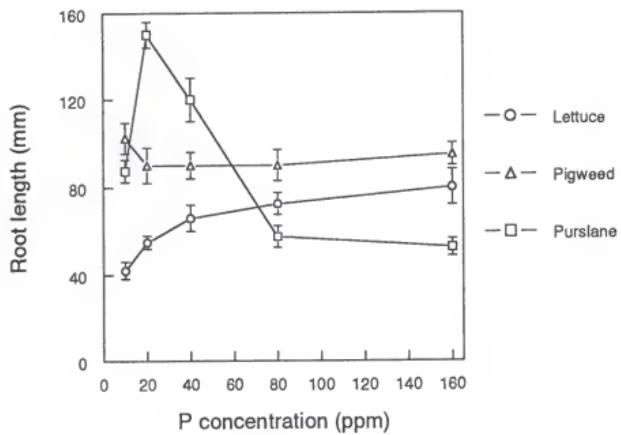
Figure 8-2. Lettuce, smooth pigweed and common purslane root length in monoculture.
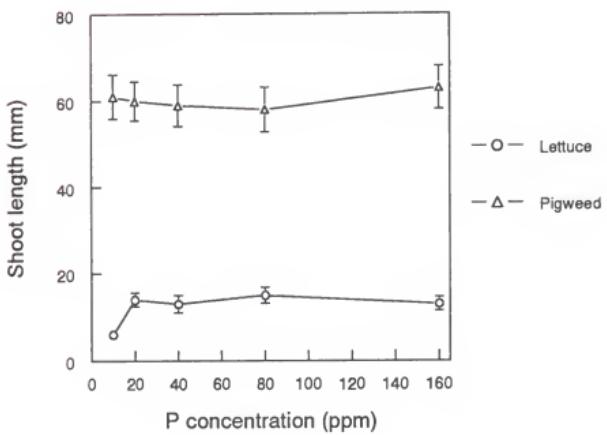
Figure 8-3. Lettuce and smooth pigweed shoot length in mixture.
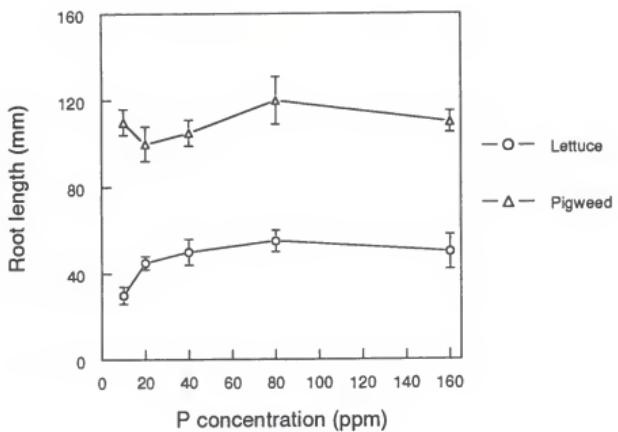
Figure 8-4. Lettuce and smooth pigweed root length in mixture.
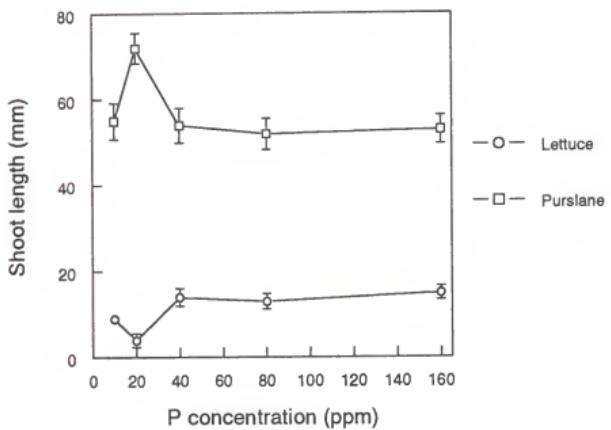
Figure 8-5. Lettuce and common purslane shoot length in mixture.
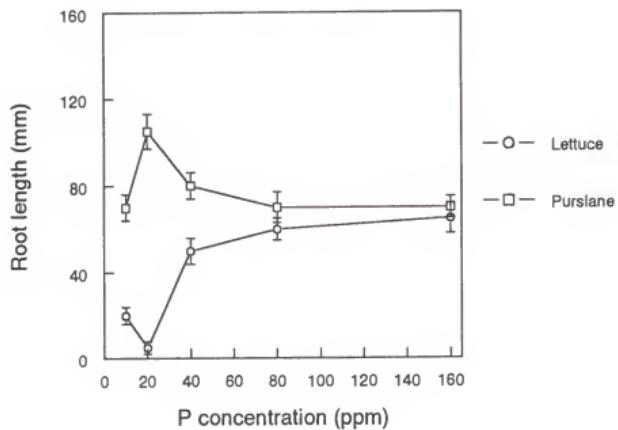
Figure 8-6. Lettuce and common purslane root length in mixture.

Data collected for shoot and root dry weight followed similar patterns as those for shoot and root length (Figures 8-7, 8-8, 8-9, 8-10, 8-11 and 8-12). This finding indicates that there was a direct correlation between shoot and root elongation of each species and their biomass accumulation.

The fact that a P concentration of 40 ppm enhanced lettuce biomass and elongation in monoculture indicated that lettuce responded to P fertility in the system by reducing the intraspecific competition for P taking place at lower P concentrations that resulted in lower biomass and elongation. Smooth pigweed as demonstrated previously does not alter its biomass accumulation through P addition. In this regard, no intraspecific competition for P between the two smooth pigweed plants occurred. On the other hand, common purslane in monoculture was shown to benefit from P concentrations of 20 ppm in terms of its biomass and elongation. Higher P concentrations resulted in smaller common purslane plants than at 10 ppm P. There are two plausible explanations for this occurrence. First, at 10 ppm, there was not enough P available for the two common purslane plants in the system (high intraspecific competition for P), therefore depressed growth resulted. Second, at higher P concentrations (80 and 160 ppm) toxicity due to the high salinity content of the solution may have affected the water status in the plants.

In lettuce-smooth pigweed mixtures, the fact that lettuce was affected negatively in terms of growth in the presence of smooth pigweed suggested that the weed was interfering with lettuce for some essential factor needed by the crop, but not needed by
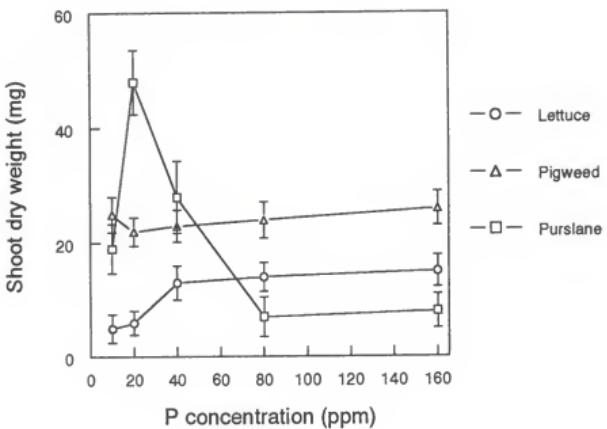
Figure 8-7. Lettuce, smooth pigweed and common purslane shoot dry weight in monoculture.
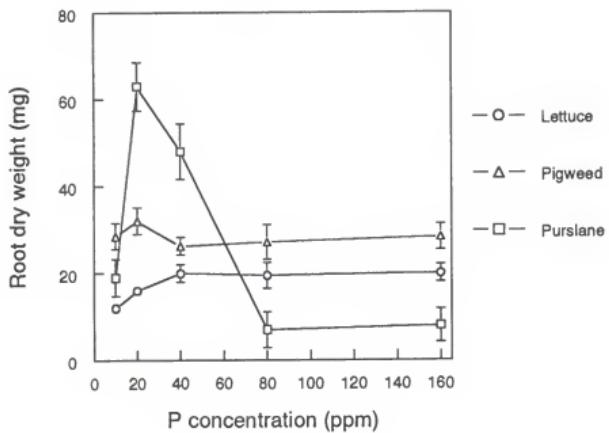
Figure 8-8. Lettuce, smooth pigweed and common purslane root dry weight in monoculture.
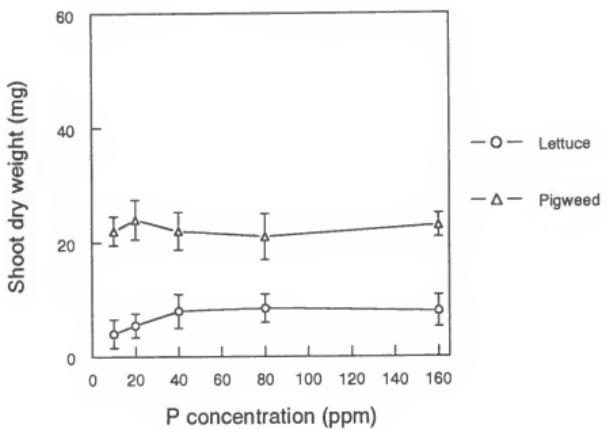
Figure 8-9. Lettuce and smooth pigweed shoot dry weight in mixture.
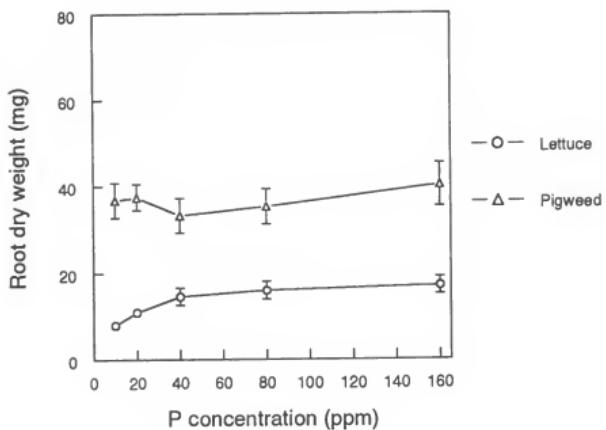
Figure 8-10. Lettuce and smooth pigweed root dry weight in mixture.
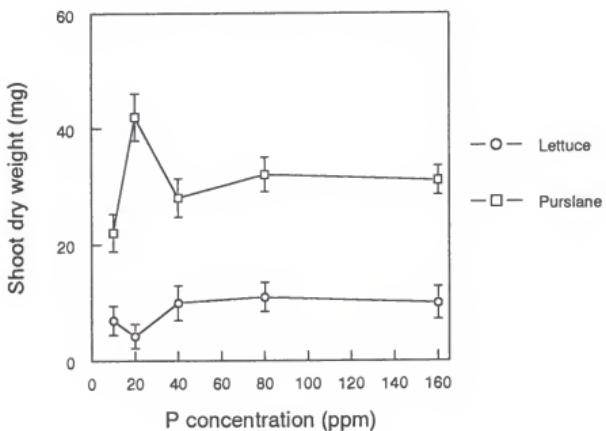
Figure 8-11. Lettuce and common purslane shoot dry weight in mixture.
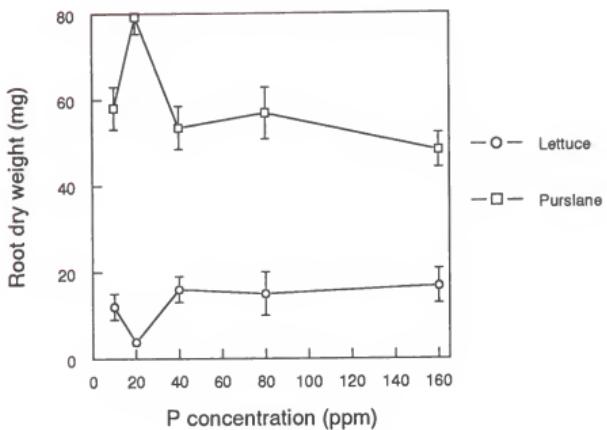
Figure 8-12. Lettuce and smooth pigweed root dry weight in mixture.

the weed. Analysis of P tissue content of lettuce and smooth pigweed indicated that P amounts in the weed increased with P concentration, providing definitive proof of luxurious consumption by smooth pigweed as one its mechanisms of interfering with lettuce growth (Figure 8-13).

In lettuce-common purslane complexes, P tissue concentration of the weed followed the same trend shown for shoot and root dry weight, where maximum P tissue content was obtained at 20 ppm (Figure 8-14). Lettuce values, declined at that P rate. These findings indicate that interspecific competition for P between common purslane and lettuce at 20 ppm was maximized. Reduction at higher P concentrations was probably due to the combined effect of two factors: a) enhanced lettuce competitive ability, and b) decreased common purslane biomass, possibly due to adverse high P effects, which may have affected the water status in the plants. From the data collected and under the conditions of these studies, it can be inferred that common purslane had a narrow range for P absorption.

Phosphorus Depletion Studies

Exponential equations characterized the P response of each species as affected by time of exposure. Depletion equation coefficients showed that common purslane was the most aggressive of the three species capturing P from a 20 ppm solution (Figure 8-15), followed by lettuce and smooth pigweed. Almost total depletion (0.23 ppm P remaining) of the P in solution was achieved with common purslane at 14400 min (1 day) of root exposure to the solution. At the same time, lettuce still had 2 ppm P in solution.
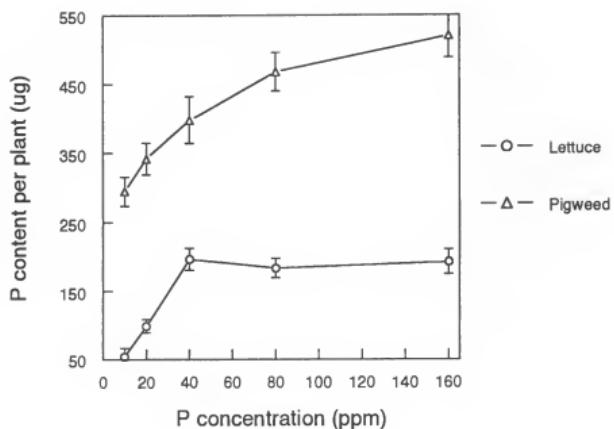
Figure 8-13. Lettuce and smooth pigweed phosphorus (P) content per plant in mixture.
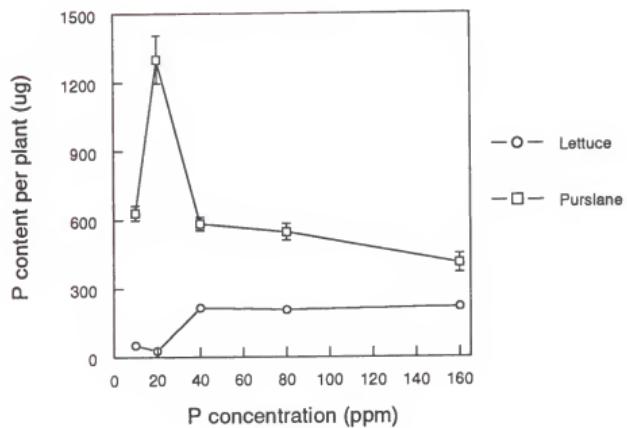
Figure 8-14. Lettuce and common purslane phosphorus (P) content per plant in mixture.
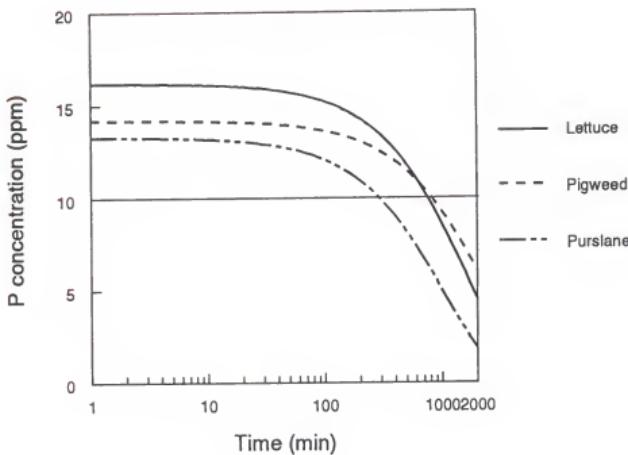
Figure 8-15. Lettuce, smooth pigweed and common purslane depletion curves in a 20 ppm of P solution. Regression equations are $y = 16.2(e^{(-0.000630x)})$, $r^2 = 0.85$ for lettuce, $y = 14.2(e^{(-0.000425x)})$, $r^2 = 0.91$ for pigweed, and $y = 13.3(e^{(-0.000968x)})$, $r^2 = 0.94$ for purslane.

After 1 min of root submersion, both weeds had absorbed approximately 7.5 ppm P from the solution, whereas lettuce had obtained only 2.5 ppm P. This rapid absorption may be due to the tendency of the plants to restore the water lost in the root cleaning process carrying P inside. Because the root system of both weeds was more profuse than the crop's, larger amounts of water and P may have been absorbed during the first minute. However, as the water status inside the plants was restored, the absorption process slowed until it reached a rapid P absorption phase. Time values for depletion of 50% of the solution were 160, 370 and 400 min for common purslane, smooth pigweed and lettuce, respectively.

Under the conditions of these studies, it appears that common purslane has the ability to capture P more rapidly than lettuce, giving the weed an edge in its competitiveness. Even a no-P-responsive weed such as smooth pigweed was shown to be capturing P at a high rate, affecting the P amount available for lettuce absorption.

Conclusions

The data discussed herein led to the rejection of the null hypothesis and the acceptance of the alternative hypothesis that: a) There were effects of the weeds involved in the P amounts absorbed by lettuce. As previously presented, smooth pigweed and common purslane absorb P at the expense of lettuce. Smooth pigweed interferes through luxurious consumption of this nutrient, whereas common purslane utilizes this element for growth. Both processes represent important mechanisms of interference by the weeds.

CHAPTER 9
SUMMARY AND CONCLUSIONS

Greenhouse replacement series studies showed that both smooth pigweed and common purslane are more competitive than lettuce regardless of P rate. However, high P fertility enhanced lettuce competitive ability against smooth pigweed, whereas no effect on the lettuce was observed in lettuce-common purslane mixtures with high P rates. Common purslane was responsive to P fertilization, while smooth pigweed was not.

Density and removal time additive studies conducted under field conditions demonstrated that banding P beneath lettuce rows as opposed to broadcasting reduced the smooth pigweed critical density necessary to significantly reduce lettuce yield and quality, as well as increasing the period of time before the weed must be removed without significant yield loss. On the other hand, P fertilizer application method had no effect on common purslane critical density, while critical removal time was increased when P was banded compared with broadcast application. In general, P banded treatments resulted in higher lettuce yields compared with broadcast applications, regardless of the weed density or removal time.

Above and below ground partitioning studies showed that smooth pigweed interference with lettuce occurs through two mechanisms. Light interception appeared to be the primary mechanism of interference, whereas luxurious P consumption was a

secondary mechanism. Common purslane interference is primarily characterized by P absorption at the expense of lettuce, followed by increased biomass accumulation. This resulted in larger weed canopies that eventually shaded shorter lettuce plants. The P depletion studies revealed that common purslane absorbed P more rapidly than lettuce, whereas lettuce acquired this essential element faster than smooth pigweed.

Phosphorus fertilization strategies may be utilized effectively by producers to reduce and delay the negative impact of smooth pigweed and common purslane in lettuce production.

REFERENCES

Anderson, W. P. 1983. Weed Science: Principles. St. Paul, MN: West Publ. Co.

Berendse, F. and W. T. Elberse. 1990. Competition and nutrient availability in heartland and grassland ecosystems. *In* J. B. Grace and D. Tilman (eds.). Perspectives on Plant Competition. San Diego, CA: Academic Press. pp. 93-116.

Bewick, T. A., D. G. Shilling, J. A. Dusky and D. Williams. Effects of celery (*Apium graveolens*) root residue on growth of various crops and weeds. Weed Technol. 8:625-629.

Bleasdale, J. K. and J. A. Nelder. 1960. Plant population and crop yield. Nature 188:342.

Brady, N. C. 1990. The Nature and Properties of Soils. New York, NY: MacMillan Publ. Co.

Burkholder, P. R. 1952. Cooperation and conflict among primitive organisms. Am. Sci. 40:601-631.

Carlson, H. L. and J. E. Hill. 1986. Wild oat (*Avena fatua*) competition with spring wheat: Effects of nitrogen fertilization. Weed Sci. 34:29-33.

Colvin, D. L. and L. B. McCarty. 1996. Principles of weed management. *In* D. L. Colvin (ed.). 1996 Florida Weed Management Guide. Gainesville, FL:Univ. of Florida. pp. 1-9.

Cousens, R. 1991. Aspects of the design and interpretation of competition (interference) experiments. Weed Technol. 5:664-673.

Cousens, R. and M. Mortimer. 1995. Dynamics of Weed Populations. Melbourne, Australia: Cambridge Univ. Press. 332 pp.

de Wit, C.T. 1960. On competition. Versl. Landbouwk. Onderz. 66:1-82.

DiTomaso, J. M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491-497.

Doty, W. L. 1990. All About Vegetables. San Ramon, CA: Ortho Books.

Dusky, J. A. and W. M. Stall. 1988. Evaluation of herbicides for weed control in Florida lettuce production. Proc. Fla. State Hort. Soc. 101:367-370.

Firbank, L. G. and A. R. Watkinson. 1990. On the effects of competition: From monocultures to mixtures. *In* J. B. Grace and D. Tilman (eds.). Perspectives on Plant Competition. San Diego, CA: Academic Press. pp. 165-192.

Florida Agricultural Extension Service. 1984. Weeds of the Southern United States. Gainesville, FL: Univ. Florida.

Florida Agricultural Statistics Service. 1997. Florida Agricultural Statistics: Vegetable Summary 1995-96. Orlando, FL: Florida Agricultural Statistics Service. 72 pp.

Foster, R., E. Knake, R. H. McCarty and J. J. Mortvedt. 1996. Weed Control Manual. Vol. 30. Willoughby, OH: Meinster Publ. Co. 538 pp.

Fuerst, E. P. and A. R. Putnam. 1983. Separating the competitive and allelopathic components of interference: theoretical principles. J. Chem. Ecol. 9:937-944.

Goldberg, D. E. 1990. Components of resource competition in plant communities. *In* J. B. Grace and D. Tilman (eds.). Perspectives on Plant Competition. New York, NY: Academic Press. pp. 27-49.

Grime, J. P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am. Nat. 111:1169-1194.

Groves, R. H. and J. D. Williams. 1975. Growth of skeleton weed (*Chondrilla juncea* L.) as affected by growth of subterranean clover (*Trifolium subterraneum* L.) and infection by *Puccinia chondrilla* Bubak and Syd. Aust. J. Agric. Res. 26:975-983.

Guenkov, G. 1966. Manual de horticultura cubana. Havana, Cuba: Edit. Organismos. 350 pp.

Hartmann, H. T., W. J. Flocker and A. M. Kofranek. 1984. Plant Science: Growth, Development, and Utilization of Cultivated Plants. Englewood Cliffs, NJ: Prentice-Hall, Inc., pp. 563-567.

Hochmuth, G., E. Hanlon, R. Nagata, G. Snyder and T. Schueneman. 1994. Crisphead Lettuce: Fertilization Recommendations for Crisphead Lettuce Grown on Organic Soils in Florida. Fla. Coop. Ext. Serv. Bull. SP-153. 25 pp.

Holm, L. G., D. G. Plucknett, J. V. Pancho and J. P. Herberger. 1991. The World's Worst Weeds: Distribution and Biology. Malabar, FL: Krieger Publ. Co. 550 pp.

Izuno, F. T., C. A. Sanchez, F. J. Coale, A. B. Bottcher and D. B. Jones. 1991. Phosphorus concentrations in drainage water in the Everglades Agricultural Area. J. Environ. Qual. 20(3) 608-619.

Janick, J. 1986. Horticultural Science. New York, NY: W. H. Freeman and Co.

Jolliffe, P. A., A. N. Minjas and V. C. Runeckles. 1984. A reinterpretation of yield relationship in replacement series experiments. J. Appl. Ecol. 21:227-243.

Kira, T., H. Ogawa and N. Sakazaki. 1953. Intraspecific competition among higher plants. I. Competition-yield-density interrrelationships in regularly dispersed populations. J. Inst. Polytech. Osaka City Univ. Ser. D 4, 1-16.

Ku, S. B., Y. J. Shieh, B. J. Reger and C. C. Black. 1981. Photosynthetic characteristics of *Portulaca grandifolia*, a succulent C_4 dicot. Plant Physiol. 68:1073.

Liebman, M. and R. H. Robicheaux. 1990. Competition by barley and pea against mustard: Effects on resource acquisition, photosynthesis and yield. Agric. Ecosys. Environ, 31:155-172.

Lynne, G. D., T. H. Spreen and R. A. Solove. 1982. Cost effectiveness in water quality improvement from agricultural areas. Food and Res. Econ. Dept. Bull., Univ. of Florida. 211:32.

Martin, A. C. 1972. Weeds. Racine, WI: Golden Press, Western Publishing Company, Inc., pp. 48-52.

Maynard, D., G. Hochmuth, C. Vavrina, W. Stall, T. Kucharek, F. Johnson and T. Taylor. 1995. Lettuce, endive and escarole production in Florida. *In* D. N. Maynard and G. J. Hochmuth (eds.). Vegetable Production Guide for Florida. Gainesville, FL: Fla. Coop. Ext. Serv. Rep. SP-170. pp. 185-193.

McWhorter, C. G. and W. C. Shaw. 1982. Research needs for integrated weed management systems. Weed Sci. 30 (supl.):40-45.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chem. Acta 27:31-36.

Murphy, T. R., D. L. Colvin, R. Dickens, J. W. Everest, D. Hall and L. B. McCarty. 1994. Weeds of Southern Turfgrasses. Gainesville, FL: Univ. Florida, pp. 72, 168.

Okafor, L. I. and S. K. DeDatta. 1976. Competition between upland rice and purple nutsedge for nitrogen, moisture and light. Weed Sci. 24:43-46.

Patterson, D. T. 1985. Comparative ecophysiology of weeds and crops. *In* S. O. Duke (ed.). Weed Physiology, Vol. 1, Reproduction and Ecophysiology. Boca Raton, FL: CRC Press, Inc. pp. 101-129.

Patterson, D. T. 1986. Allelopathy. *In* N. D. Camper (ed.) Research Methods in Weed Science. Champaign, IL: Southern Weed Science Soc. pp. 111-134.

Peirce, L. 1984. Vegetables: Characteristics, Production and Marketing. New York, NY: John Wiley and Sons.

Radosevich, S. R. 1987. Methods to study interactions among crops and weeds. Weed Technol. 1:190-198.

Radosevich, S., J. Holt and C. Ghersa. 1997. Weed Ecology: Implications for Management. New York, NY: John Wiley and Sons, Inc.

Rasmussen, P. E. 1995. Effects of fertilizer and stubble burning on downy brome competition in winter wheat. Comm. Soil Sci. and Plant Anal. 26:951-960.

Rejmanek, M., G. R. Robinson and E. Rejmankova. 1989. Weed-crop competition: Experimental designs and models for data analysis. Weed Sci. 37:276-284.

Roush, M. L., S. R. Radosevich, R. G. Wagner, B. D. Maxwell and T. D. Petersen. 1989. A comparison of methods for measuring effects of density and proportion in plant competition experiments. Weed Sci. 37:268-275.

Salisbury, F. and C. Ross. 1984. Plant Physiology. Belmont, CA: Wadsworth Publ. Co. 540 pp.

Sample, E. C., R. J. Soper, and G. J. Racz. 1980. Reactions of phosphate fertilizers in soils. *In* F. E. Khasawneh et al. (eds.) The Role of Phosphorus in Agriculture. Madison, WI: ASA, CSSA, SSSA, pp. 263-304.

Sanchez, C. A., P. S. Porter and M. F. Ulloa. 1991. Relative efficiency of broadcast and banded phosphorus for sweet corn produced on histosols. Soil. Sci. Soc. of Am. J. 55(3):871-875.

Sanchez, C. A. and P. S. Porter. 1994. Phosphorus in the organic soils of the EAA. *In* A. B. Bottcher and F. T. Izuno (eds.). Everglades Agricultural Area: Water, Soil, Crop and Environmental Management. Gainesville, FL: Univ. Press of Florida, pp. 62-84.

Sanchez, C. A. 1991. Soil-Testing and Fertilization Recommendations for Crop Production on Organic Soils in Florida. Fla. Coop. Ext. Serv. Bull. 876.

Sanchez, C. A., S. Swanson and P. S. Porter. 1990. Banding P to improve fertilizer use efficiency of lettuce. J. Am. Soc. Hort. Sci. 115:581-584.

SAS Institute Inc. 1987. The ANOVA procedure. p. 125-154. In: SAS/STAT guide for personal computers, ver. 6 ed. Cary, NC: SAS Inst., Inc.

Shinozaki, K. and T. Kira. 1956. Intraspecific competition among higher plants. VII. Logistic theory of the C-D effect, J. Inst. Polytech., Osaka City Univ. Ser. D 7, 35-72.

Shrefler, J. W., D. G. Shilling, J. A. Dusky and B. J. Brecke. 1994a. Influence of phosphorus fertility on intra- and interspecific interference between lettuce (*Lactuca sativa*) and spiny amaranth (*Amaranthus spinosus*). Weed Sci. 42:574-578.

Shrefler, J. W., J. A. Dusky, D. G. Shilling, B. J. Brecke and C. A. Sanchez. 1994b. Effects of phosphorus fertility on competition between lettuce (*Lactuca sativa*) and spiny amaranth (*Amaranthus spinosus*). Weed Sci. 42:556-560.

Silvertown, J. W. 1987. Introduction to Plant Population Ecology. Essex, England: Longman Sci. and Tech. 229 pp.

Snyder, G. H. 1994. Soils of the EAA. *In* A. B. Bottcher and F. T. Izuno. Everglades Agricultural Area: Water, Soil, Crop and Environmental Management. Gainesville, FL: Univ. Press of Florida., pp. 27-41.

Southern Weed Science Society. 1994. Weed Identification Guide. Champaign, IL: South.Weed Sci. Soc.

Stall, W. M., J. A. Dusky and J. P. Gilreath. 1996. Estimated effectiveness of recommended herbicides on selected common weeds in Florida vegetables. *In* D. L. Colvin (ed.). 1996 Florida Weed Management Guide. Gainesville, FL: Univ. of Florida. pp. 313-316.

Swiader, J. M., G. W. Ware and J. P. McCollum. 1992. Producing Vegetable Crops. Danville, IL: Interstate Publ., Inc.

Tilman, D. 1982. Resource Competition and Community Structure. Princeton, NJ: Monogr. Pop. Biol. Princeton Univ. Press.

United States Department of Agriculture. 1985. United States Standards for Grades of Lettuce. Washington, DC: Agricultural Marketing Service. 125 pp.

United States Department of Agriculture. 1997. Vegetables: 1996 Summary. Washington, DC: National Agricultural Statistics Service. 78 pp.

Windemuller, P., D. L. Anderson, R. H. Aalderink, W. Abtew and J. Obeysekera. 1997. Modeling flow in the Everglades Agricultural Area irrigation/drainage canal network. J. Am. Water Resources Assoc. 33(1):21-34.

Wolf, B. 1982. A comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. Commun. Soil. Sci. Plant. Anal. 13:1035-1059.

BIOGRAPHICAL SKETCH

I was born in Santo Domingo, Dominican Republic, on October 29, 1968 as the oldest son of three children procreated by Mercedes Gomez and Marcelino Santos. At the age of 12, I started technical studies in agronomy at "Loyola" Polytechnical Institute in San Cristobal, Dominican Republic, where I graduated in 1986 after five years of obtaining highest honors for academic achievements. In 1988, I attended the "Pedro Henriquez Ureña" National University in Santo Domingo, where in 1990 I obtained a diploma as agricultural engineering "magna cum laude" with a major in crop production. One year later, a diploma in Advanced Studies in Forestry "magna cum laude" was awarded to me by the same university.

At the beginning of 1993, after working as an advisor for several different agricultural companies and as an assistant to the head of the Horticultural Unit at the Southern Center for Agricultural Development, I received a scholarship to pursue a master's degree in horticultural sciences at the University of Florida under Dr. Thomas Bewick's direction. From May to August 1993, I attended to the English Language Training and Orientation program of the University of Pittsburgh. It was during this period of time that I met my wife, formerly Michelle Middleton, who has inspired me everyday since.

In May 1995, a master's degree was awarded to me, while I was accepted to continue my studies in the same department toward the doctoral degree with Dr. Joan A. Dusky as my major professor. Nowadays, my wife, my son and I are planning to travel to my native country to serve as agricultural advisor and teacher in the areas of weed science, crop nutrition, and olericulture.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Joan A. Dusky
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William M. Stall
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.
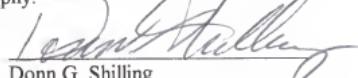
Donn G. Shilling
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.
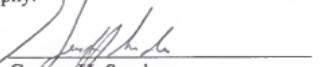
George H. Snyder
Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Thomas A. Bewick
Professor, Cranberry Experiment
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    Massachusetts

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May, 1998
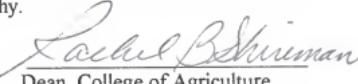
Rachel B Shureman
Dean, College of Agriculture

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Dean, Graduate School